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Suitability of Potential Alternatives to Pyrotechnic Distress Signals

Interim Report

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Homeland Security

N O T I C E

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16. Abstract (MAXIMUM 200 WORDS)

Purpose: To determine the potential suitability of electronic alternatives to pyrotechnic visual distress signals through the evaluation of the effectiveness of presently-available LED (and other) devices as visual distress signal devices (VDSDs).

Methods: Requirements workshop, market research, field testing to assess visibility at different ranges, paired comparison testing to assess attention-getting characteristics, and ergonomic testing.

Results: Lab test results predicting device visual detection range based on effective intensity compared well with results obtained from field testing. Light-emitting diode (LED) devices tested consistently better than incandescent or flashtube devices. Color and flash pattern (rapid flash rate or S-O-S characteristic) improved the perceptive performance of the devices.

Conclusions: LED devices have potential as an alternative to pyrotechnic VDSDs. Desirable VDSD characteristics identified in this report can be used to inform future VDSD performance requirements development. Intensity profiles (omni-directional versus narrow beam) must be considered when comparing predicted visual detection ranges. Detection ranges predicted from laboratory-measured Effective Intensity of white VDSDs compared favorably with ranges observed during field tests. This indicates that Effective Intensity can be used in lieu of field tests to predict the visual detection range of VDSDs under specified meteorological conditions.

17. Key Words Visual distress signal device (VDSD), effective intensity, intensity profile, signal characteristic, flash pattern, modified Allard method, non-pyrotechnic, ergonomic, LED, flashtube	**18. Distribution Statement** **Distribution Statement A:** Approved for public release; distribution is unlimited.		
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EXECUTIVE SUMMARY

Vessels must comply with a number of distress notification carriage requirements that include visual and audible distress signal devices. Commercial vessels or those subject to the Safety of Life at Sea (SOLAS) Conventions (i.e., vessels on international voyages) are additionally required to carry electronic devices such as radios and EPIRBs, or are required to adhere to the Global Maritime Distress and Safety System (GMDSS). Mariners of all types need effective signals to indicate distress (the "notification" phase). Signal devices are also essential to help rescuers actually find a distressed vessel or people in the water (the "locate" phase). This project focuses on devices for use during the locate phase, as a single device might not be suitable for both uses.

Pyrotechnic flares (visual distress signal devices or VDSDs) are commonly used by mariners to signal distress. Flares have drawbacks, however; they can injure the user, cause fire on a vessel, and they present significant storage and disposal problems. Also, the Coast Guard (CG) Office of Search and Rescue (CG-534) suggested that it may be problematic that there are requirements to carry devices (flares) that may not be as effective as others (i.e., marine electronics), but no requirements to carry the more effective means. In conjunction with CG-534, the Lifesaving and Fire Safety Division (CG-5214) and the Boating Safety Division (CG-5422) sought support from the CG Research & Development Center (RDC) in determining appropriate criteria to evaluate light emitting diode (LED) devices as potential maritime distress signals.

The purpose of this study was to conduct lab tests, field demonstrations, and ergonomic tests of a selected group of non-pyrotechnic signal devices, and identify the characteristics that make them more detectable and attention-getting. Prior to this study, the RDC conducted a VDSD Functional Requirements Workshop, issued a Request for Information (RFI), and performed extensive market research to determine candidate signal devices.

The project team selected a group of LED, flashtube, and incandescent-based devices to obtain photometric data. An understanding of the physical (beam width, peak intensity, temporal characteristics, etc.) and perceptual (color, effective intensity) aspects of these devices allowed the project team to select a subset of devices for further evaluation.

Following the lab tests, the project team designed and conducted two field demonstrations. The first demonstration assessed individual devices to determine the most effective signal characteristics based on detectable range, ability to attract attention, and ability to distinguish the signal against background lighting. A second demonstration used a subset of the devices to compare the most effective characteristics, head-to-head. Finally, a separate evaluation looked at device ergonomics to help understand the physical aspects of the devices that make them easier to use.

Throughout all of the tests, the objective was to identify characteristics of high-performing devices to support developing performance requirements for future VDSDs. The primary finding from analysis of the data for white signal lights is that the most effective VDSDs had, in addition to other key attributes, the highest effective intensities; thus the lab results were consistent with the field test results. This suggests that lab tests, where effective intensity is calculated from quantitative measurements of peak intensity and flash duration, may be used in the place of field tests to estimate the range at which devices can be detected. When comparing VDSD detection ranges it is important to consider whether the device presents an omnidirectional or narrow beam intensity profile. Among the signals tested, LED devices consistently outperformed devices using flashtube or incandescent technology. This is due to the higher effective

intensities presented by the LED devices as compared with incandescent and flashtube devices. White and red signal colors with moderate to rapid flash rates were preferred by test observers.

In the ergonomic testing, the considerable variety of features and physical characteristics of the devices tested served to identify desirable traits, but also to highlight the challenges present in choosing one desirable feature over another. Identifying "good" traits can be done without difficulty; however, within the confines of the design envelope, one desirable feature is a tradeoff against another desirable feature. The tradeoff choices are sensitive to the underlying scenario and assumptions that support it; a desirable feature under one distress scenario may be undesirable in another scenario.

The project team recommends further lab testing to determine optimal signal characteristics, including:

- Color: a more controlled study of color vs. intensity is needed to determine if certain colors are more effective or attention-getting.
- Flash rates: although faster flash rates were preferred, data were limited to few observer comments, and many factors exist that will affect how "faster" is defined.
- Flash patterns (e.g., the Morse code distress signal S-O-S and other irregular patterns) deserve additional study. Although the data suggest that irregular flash patterns were more conspicuous to observers, investigation was limited to only two types of irregular flash patterns.

Also, ergonomics is a large area to investigate further, however, underlying scenario(s) and assumptions should first be refined to determine which ergonomic qualities are more important. After making these trade-offs, ergonomic design aspects can be prioritized for study in a more focused manner through additional human factors testing.

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

μsec	Microsecond
AtoN	Aids to Navigation
cd	Candela
CFR	Code of Federal Regulations
CG	Coast Guard
COI	Critical operational issue
COLREGS	Collision Regulations
d	Distance
DOT	Department of Transportation
E	Illuminance
EDT	Eastern daylight time
EPIRB	Emergency Position-Indicating Radio Beacon
fc	Footcandle
fL	Foot-Lambert
GFI	Government-furnished information
GMDSS	Global Maritime Distress and Safety System
I	Luminous intensity
IALA	International Association of Lighthouse Authorities
LED	Light-emitting diode
LLNR	Light List Number
ms	Millisecond
NHTSA	National Highway Traffic Safety Administration
NM	Nautical mile
NPFG	Non-Pyrotechnic Flash Bang
PFD	Personal flotation device
PPE	Personal protective equipment
R&D	Research & development
RDC	Research & Development Center
RFI	Request for Information
SAIC	Science Applications International Corporation
SAR	Search and rescue
SAT	Satisfactory
sec	Second
SME	Subject matter expert
SOLAS	Safety of Life at Sea
S-O-S	Distress signal in Morse code
TC	Test Coordinator
TD	Test Director
UNSAT	Unsatisfactory
USCG	United States Coast Guard
VDSD	Visual distress signal device

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1 INTRODUCTION

Mariners have long relied on signaling devices to provide initial notification of a distress (the *notification* phase), and to help rescue personnel locate a distressed vessel and victims in the water (the *locate* phase). Vessels must comply with a number of distress notification and carriage requirements that include visual and audible distress signal devices. Commercial vessels and those subject to the Safety of Life at Sea (SOLAS) Conventions (i.e., vessels on international voyages) are additionally required to carry electronic devices such as radios and Emergency Position-Indicating Radio Beacons (EPIRBs), or are required to adhere to the Global Maritime Distress and Safety System (GMDSS). No recreational vessels are required to carry radios; however, most are required to carry visual and audible distress devices. Beyond carriage requirements, vessels may also carry other distress notification devices voluntarily.

A commonly-used visual distress signal device (VDSD) is the pyrotechnic flare. Although widely used, pyrotechnic devices, by nature, present certain hazards: they can burn/injure the user, start a fire on a vessel, and they present significant storage and disposal problems (e.g., perchlorate-based pyrotechnics). Recognizing the hazards associated with flares, the Coast Guard (CG) Research & Development Center (RDC), under the sponsorship of the Coast Guard Office of Search and Rescue (CG-534), the Life Saving & Fire Safety Division (CG-5214), and the Boating Safety Division (CG-5422), began exploring safer, more environmentally-friendly alternatives to flares. A chief concern was that some of the devices currently mandated for use might not be as visually effective as other devices. The Coast Guard would like to review available signal devices and revise its carriage requirements, if needed, to ensure that mandated devices are effective VDSDs.

1.1 Background

1.1.1 VDSD Functional Requirements Workshop

In March 2011, the RDC held a workshop to determine functional requirements for VDSDs. Workshop participants included: CG Offices which regulate signal devices and develop CG policies for search and rescue (SAR); personnel from field offices who are on the "front lines" of SAR and depend upon effective VDSDs to find persons in distress; Navy and industry personnel with an interest in VDSDs; and RDC personnel. The participants reviewed current distress alert, notification, and location methods, discussing strengths and weakness. Mr. Thomas A. Apple (Combatant Craft Division, Naval Surface Warfare Center, Carderock Division Detachment Norfolk) briefed attendees on recent Navy studies of non-pyrotechnic signals (Melwani, 2009). After considering the purposes of, and needs for, VDSDs, the workshop participants developed a set of functional requirements for these devices. Those requirements were used to generate critical operational issues (COIs; see Appendix. A) that directed the testing done in the current project.

1.1.2 Signal Characteristics for Conspicuity

The effectiveness of a VDSD, as with any visual signal, is dependent on the ability of the observer to see and understand the light as a "signal." The VDSD must have characteristics that allow it to be seen in the visual environment (e.g., at night, surrounded by the lights of a busy harbor; or in daylight amid boat traffic and reflections off the water). An effective VDSD must be large enough and intense enough to be seen at a sufficient distance to enable effective SAR operations. The spectral characteristics ("color") of the light are important, as daytime and nighttime vision are most sensitive to different parts of the visible spectrum. Also, the signal needs to be "meaningful": the observer has expectations related to what constitutes a "distress" signal. To the extent possible, an effective VDSD must align with these expectations and be

distinguishable from other light sources in the environment so that even a less-trained, tired, or less-attentive observer will "see" the light and respond appropriately. These are some of the factors associated with "conspicuity."

In the 1990s, the need to assess the visibility of the lights used on aids to navigation spawned a number of studies about what makes a light conspicuous (i.e., noticed, attention-getting). Several of these factors are summarized by Laxar & Benoit (1993). Some of these factors are intuitive: larger, brighter lights tend to be more conspicuous than smaller, dimmer lights. And while most people have probably noticed that flashing lights are generally more attention-getting than are steady lights, Laxar & Benoit determined that the conspicuity of flashing lights is related to flash frequency and duty cycle. In their tests of flash rates from 0.33 Hz (Hertz; or cycles per second) to 4.0 Hz, the faster the flash, the more conspicuous. Also, they found that conspicuity increased at lower duty cycles (shorter "on" times and longer "off" times). Signal motion is another eye-catching feature.

Conspicuity is not just an attribute of the signal itself; it also depends on the characteristics of the background. For instance, a flashing red light against a stark, dark background will be very conspicuous. But that same signal, against a background of other red, flashing lights will be very hard to pick out. Wagner & Laxar (1996) showed that signals which had different characteristics than the background were easier to detect. For example, lights at an oblique orientation (tilted at 45°) were easier to detect against a background of horizontal and vertical light patterns (as might typically be seen along the coast). They also found that a pair of lights flashing in synchrony were more conspicuous than either a single flashing light or a pair of lights which alternated.

From the work cited above, we can predict some of the characteristics that should make a distress signal easy to see and easy to distinguish from other lights in the environment. It should be bright, large, flash quickly (about 4 Hz), and have a short duty cycle. If possible, the device might have two or more visually-distinct lights that flash in synchrony.

1.1.3 Types of VDSDs on the Market

An early stage of the project effort included identifying light-signal devices available off the shelf. To complete this, the RDC issued a "request for information" (RFI) concerning such devices. In part this was to identify and help with later procurement of a representative cross section of commercially-available, electric visual signaling or marker devices. Specifically, the RFI was a "market research effort to assess technologies that would meet visual distress signal requirements as alternatives to pyrotechnic Visual Distress Signal Devices (VDSD)." The market research was intended to identify both operational and state-of-the-art technologies. This distinction between "operational" and "state-of-the-art" allowed for existing technologies and equipment used in commercial and/or Government application, and also for proven and near-proven technologies that can be developed for operational use in the next 30 to 36 months.

In actuality, responses to the RFI yielded only a relatively small number of devices that were later chosen for testing. One manufacturer offered a device in four, color variants and another offered three laser devices. The project did receive information on two "developmental" devices, both later included in testing. The project team found 13 other devices through marine supply catalogs.

1.1.4 Existing Standards for VDSDs

A literature review was conducted to identify VDSD standards, and also to assist in developing Critical Operational Issues (COIs). COIs formed the basis for designing the survey forms and test schedules for the individual device testing, the head-to-head comparison testing, and the ergonomic testing. For more on the COIs, see the methodology sections for the field and ergonomics tests. The complete list of COIs are provided in Appendix A.

Numerous standards applicable to pyrotechnic devices were identified, however, only Electric Distress Light for Boats (46 Code of Federal Regulations (CFR) Subpart 161.013) (Appendix B) applied to non-pyrotechnic distress signals. 46 CFR 161.013 is the standard for approval of boat electronic distress marker lights that are authorized to meet the requirements in lieu of night flares on recreational boats 16' or more in length at all times, as well as commercial fishing vessels when operating within 3 miles of the coastline. The light is not authorized as a substitute for pyrotechnics in other situations or for other vessels.

Additionally, Inland Navigation Rule 37 (33 CFR 83.37), which addresses distress signals, authorizes the use of a high intensity white light flashing at regular intervals from 50 to 70 times per minute (33 CFR 87.1(p)) in Inland Waters (high intensity not defined). This authorization does not, however, extend to vessels outside of Inland Waters; i.e., is not authorized in the International Regulations for Preventing Collisions at Sea (COLREGS) (Appendix B).

1.2 Purpose

The purpose of this study was to perform an exploratory examination of non-pyrotechnic VDSDs to see whether they appear sufficiently effective to warrant a more thorough investigation. A secondary purpose was to identify characteristics of these alternative devices which appear to be related to their visual effectiveness/conspicuity.

1.3 Scope

This report presents the results of lab and field testing on a collection of non-pyrotechnic VDSDs to determine desirable characteristics for an effective and user-friendly device. Because there may be different VDSD characteristics needed for the NOTIFICATION vs. LOCATE phases of search and rescue, this project focused on the use of VDSDs in the LOCATE phase of a distress (i.e., we considered the use of alternative, non-pyrotechnic VDSDs to be used by a person in distress to assist rescuers in locating them). Further, we restricted our study to the use of these devices for nighttime location, since this is when victims in distress are the most difficult to find, and when visual signal devices are most useful. (To be conspicuous under daytime conditions, which have greater ambient light, it is better that visual signals rely on reflected or ambient sunlight for their effectiveness, e.g., a signal mirror or fluorescent flag.)

The study focused on two primary areas: visual characteristics of the signals (e.g., intensity, conspicuity); and the ergonomics of the devices (e.g., ease of use, weight, durability). Some of the requirements developed at the VDSD Functional Requirements Workshop were used to evaluate the visual characteristics and ergonomics of the devices.

The study of visual characteristics was actually a series of three tests which built upon one another:

- Lab Testing. The first test entailed laboratory measurements of the light output of each device. Measurements included the peak luminous intensity (the brightest output); the angular luminous intensity profile (how light intensity varies vertically and horizontally); and the temporal luminous intensity profile (how intensity varies over time). From the lab measurements, it was possible to calculate the "nominal range," that is, the distance at which each signal would be expected to be "dependably detected" (i.e., at a retinal illuminance of 0.2 microlux, which allows signal color and flash duration to be discernable; see IALA (2008a, 2008b) under specified meteorological conditions. The use of nominal range allows for a direct comparison of the predicted visibility of flashtube to that of light-emitting diodes (LEDs) and incandescent devices. The results of the lab testing were used to select a subset of the devices for field testing.
- Field Testing of Individual Devices. Whereas the lab testing resulted in predictions about the range over which the different signals could be seen, a field test was undertaken to see whether these predictions would hold up under real-world conditions. Individual signals were presented at different ranges and against two different backgrounds (very little environmental light vs. a background with many other lights present). In addition to validating the lab test results for visibility, observers also rated each signal on three aspects of conspicuity: how easy it was to see, how attention-getting it was, and how easily it was distinguished from the background. Thus, this field test provided feedback on the perceptual aspects of the signals, and allowed an initial look at what physical characteristics of the lights might be related to their conspicuity.
- Head-to-Head Testing. Based on the results of the Individual Device testing, a subset of the devices was selected for a second round of field testing. This time, the devices were tested in pairs. The objective of this test was to provide more precise feedback on those visual characteristics (brightness, flash rate, and color) which most influenced observers' perceptions of conspicuity.

The point of the visual performance testing was to take the first steps in understanding how the physical characteristics of these signals relate to their visual effectiveness/conspicuity. The longer-term goal would be to develop future performance specifications for an effective electronic VDSD.

Figure 1 shows the slate from which devices were selected for each phase of the test, along with their respective identification numbers. The identification numbers assigned to each device are used throughout this report in each of the test phases. NOTE: devices 2 and 5 initially tested so poorly, that they were removed from further tests.

Figure 1. Slate of devices tested.

2 LAB TESTING

The RDC conducted tests at its Photometric Testing Laboratory (lab) from June through September 2011 to measure the characteristics of the light field produced by 15 VDSDs in a controlled setting. This testing provided empirical data to determine the expected maximum range at which each light could be detected (luminous range of the device). This testing provided objective data for comparison with the results of subsequent subjective field tests.

Lab tests were designed so that empirical characteristics of the VDSDs measured in the lab could later be compared with subjective observations made in the field, to see if a lab protocol could be developed to adequately predict how a VDSD would perform on the water under real-world conditions. A considerable body of research already exists in the Aids to Navigation (AtoN) community, on the perception and visibility of marine signal lights as well as recommendations on methods for measuring and calculating luminous range. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) periodically reviews this research and publishes recommended procedures for characterizing marine AtoN. The following IALA recommendations were consulted for the design of the lab tests.

- E-200-2, Marine Signal Lights Part 2 - Calculation, Definition and Notation of Luminous Range, Edition 1, December 2008.
- E-200-3, Marine Signal Lights Part 3 - Measurement, Edition 1, December 2008.
- E-200-4, Marine Signal Lights Part 4 - Determination and Calculation of Effective Intensity, Edition 1, December 2008.

Drawing on the IALA literature, it was determined that effective intensity is a good predictor of luminous range (the distance that a flashing light can be seen under given atmospheric conditions). Other literature indicates that flash rate affects the conspicuity of a light as well. Flash rates of about 3-10 Hz (with duration at least 50 msec) have been recommended for attracting attention (National Highway Traffic Safety Administration (NHTSA) publication Department of Transportation (DOT) HS 809 425, pp 62).

The RDC created a sample pool of potential devices via an industry RFI bulletin and market research. Devices were selected for lab testing based upon the functional requirements list generated from the RDC Functional Requirements Workshop (U.S. Coast Guard Research & Development Center, 29-30 March 2011). Many devices submitted in the RFI results were either over the cost that the public would be expected to pay for such a device ($250 threshold set by the RDC) or could not be delivered to the RDC by the start of lab testing.

Lab testing consisted of 15 devices; however, some of the devices operate in more than one mode so that there were 18 data sets. From the 18 data sets, eight devices, exhibiting 11 modes of operation, were selected for the field test. Devices selected for the field tests collectively exhibited the following characteristics.

1. Xenon flashtube with a high effective intensity.
2. Xenon flashtube with the low effective intensity.
3. LED with a high effective intensity.
4. LED with a low effective intensity.
5. LED with a slow flash rate.
6. LED with a fast flash rate.
7. LED with a modulated flash.
8. Red, green, white, and blue LEDs.

Once the devices for the field tests were selected, luminous range (how far it can be seen under given atmospheric conditions) for each device (Table 1) was calculated for later comparison with the field test results.

2.1 Lab Methodology

The RDC measured each device to determine the average peak luminous intensity on the central axis, angular luminous intensity profile, temporal intensity distribution and signal degradation over time due to drain on the battery. Measurements were made in accordance with Section 5 (Measurement Principals), "IALA Recommendation E-200-3, Marine Signal Lights – Measurement" (IALA E-200-3, December 2008).

The calculation of effective intensity is of special interest in this study because many of the distress signals feature flashing lights. The human eye takes a certain amount of time to respond to changes in light intensity, so a flashing light source will appear less intense to an observer than a steady light with the same peak intensity, and will not be as easily detected. Effective intensity is typically calculated from the measured intensity of a flashing light by applying a function intended to model the temporal response of the eye. Effective intensity is defined as: "the luminous intensity of a fixed light which would have the same range as the flashing light". Because flashing light sources appear less intense than constant light sources with the same peak luminous intensity, the assumption is that effective intensity can be used to predict the detectable range of a flashing light. Figure 2 provides photos of the devices tested in the lab.

Figure 2. Devices tested in lab.

2.1.1 Peak Luminous Intensity Measurement

Peak luminous intensity (the maximum luminous intensity that a device produced within a given time) was measured 10 ft from the device using a photometer with an oscilloscope to record the temporal intensity profile of each device. To obtain the peak luminous intensity (I) on the central axis, the illuminance (E, in footcandles (fc)) was first determined. Luminous intensity (in candelas (cd)) was then calculated using the following equation:

$$I=E*d^2$$

where d is the distance (10 ft) between the source and detector.

Illuminance (E) could not be measured directly because of the short pulse width of VDSDs using Xenon flashtubes. Instead, the time-integrated intensity of the flash (total energy in the flash and the time duration of the flash) was measured, providing a measurement of footcandle*seconds (fc*sec). The total energy (fc*sec) of the pulse was then divided by the pulse width (in seconds (sec)) to provide the illuminance (in fc).

Ten flash intensity profiles were measured and averaged for each device to minimize the flash-to-flash variations found in some of the signals. It is notable that the flashtube output varied appreciably from flash to flash, whereas the LED flashes were quite consistent. This is important because the variability of the flashtube output can affect the calculation of effective intensity, depending on which flashes are measured and, accordingly, the flash variability is likely to affect a person's ability to detect the signal.

2.1.2 Effective Intensity Measurement

A number of mathematical models exist to derive the effective intensity of a flashing light source based on the temporal intensity distribution of the flash and its repetition rate. In this testing, the Modified Allard Method was used to derive an effective intensity from the instrumented luminous intensity measurements using a spreadsheet developed by Yoshi Ohno (Ohno, version 5.2) and distributed by the National Institute of Standards and Technology. This method calculates effective intensity, *i(t),* from instantaneous luminous intensity, *I(t)*, according to the following convolution:

$$i(t) = I(t) \otimes q(t) \qquad \text{Equation (1)}$$

Given that

$$q(t) = \frac{a}{(a+t)^2} \qquad \text{Equation (2)}$$

Where $a = 0.2$ for night time use. For a more thorough discussion of the Modified Allard Method and examples of its use, see IALA E-200-4 (December 2008).

2.1.3 Angular Luminous Intensity Profile

Angular luminous intensity profiles were measured to evaluate the impact of varying the orientation of a distress signal relative to an observer. For example, a device with a focused beam will have a relatively high luminous intensity within the focal cone, and a very low luminous intensity outside of this cone. Thus, a device with a focused beam may be very effective if the beam is oriented directly at an observer, and may be nearly undetectable if not oriented correctly. This is an important factor when these devices are used for

search and rescue (SAR), because it may be very difficult to aim a device consistently in a particular direction to attract a rescuer, given wave motion, the condition of the operator, and other circumstances in a distress situation. In addition, in many cases the operator will not know from which direction a rescuer might arrive. The angular luminous intensity profiles were measured by rotating each device through 180° (or field of illumination) while measuring its intensity 10 ft away. Figure 3, Figure 4, and Figure 5 show the beginning, center, and ending positions, respectively, for one rotation.

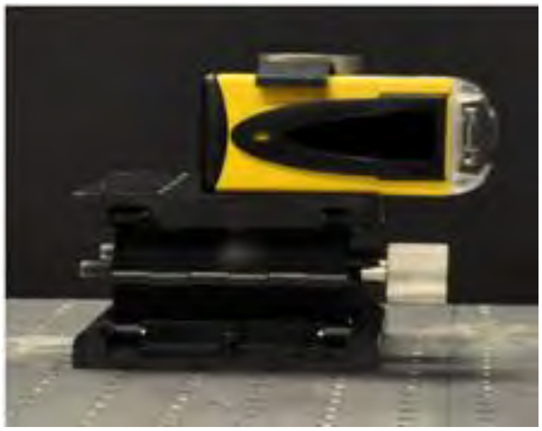

Figure 3. Light +90° off axis.

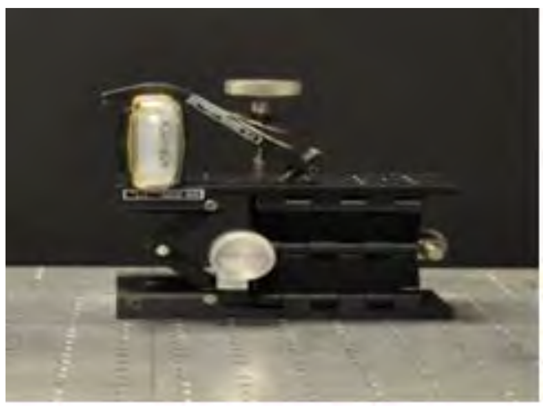

Figure 4. Light on axis.

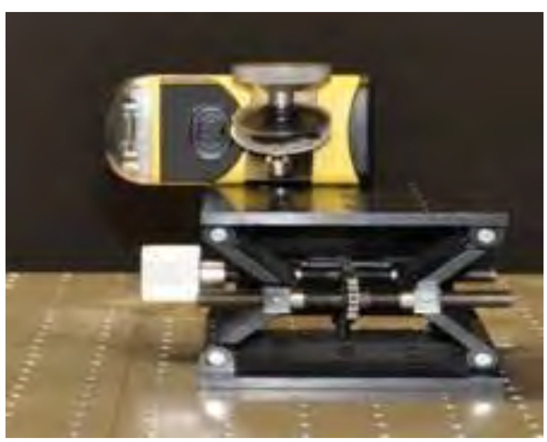

Figure 5. Light -90° off axis.

A second profile was measured after rotating the device 90° in the mount. This was done to show the intensity distribution in two planes and is deemed representative of the overall intensity distribution for the device. Figure 6 shows the mounting orientation for the horizontal and vertical orientations.

Horizontal Orientation   Vertical Orientation

Figure 6. Horizontal and vertical device configurations for testing.

2.2 Lab Test Results

Measured flash durations and peak intensities were used to calculate the effective intensities of the VDSDs. These effective intensity values were used to select the eight devices for field testing which are presented in descending order in Table 1. The flashtube-based signals exhibited the highest peak intensities, though the short duration of the flashes resulted in low effective intensities. Conversely, the incandescent signal (device 4) had the longest flash duration of the tested devices, though its low peak intensity resulted in a low effective intensity. Though the intensity of the LED signals were not as high as those utilizing flashtubes, the relatively long length of the LED flashes resulted in effective intensities an order of magnitude larger than those of flashtube based signals.

Table 1 provides the photometric data measured in the RDC Light Lab only for the devices ultimately selected for field testing. Nominal range is the distance at which the light is expected to be visible under given meteorological conditions.

Table 1. Lab test data.

Device	Type	Pulse Width (ms*)	Flashes per Minute	Illuminance (fc)	Luminous Intensity (cd)	Effective Luminous Intensity	Nominal Range (NM)
19	LED	71.0	104	0.806	81	22.4	3-3.25
20	LED	86.0	60	0.700	70	21.0	3-3.25
18	LED	44.0	121	0.864	86	17.0	2.5-3
13	LED	98.88	61	0.100	9.9	3.57	2.10
4	Incandescent	534	64	0.0116	1.2	1.16	1.00
12	Flashtube	0.0172	40	222	22,171	0.58	0.75
14	Flashtube	0.0596	42	14.7	1,471	0.177	0.40
3	Flashtube	0.0335	62	5.36	536	0.056	0.25

*millisecond

2.2.1 Lab Testing Conclusions

A few of the tested devices exhibited an illumination pattern that varied greatly in intensity depending on the orientation of the device relative to an observer. Especially notable was device 18 that had a large peak intensity in the center of a focused beam, but very low intensity outside of that narrowly focused beam. Such performance would add risk in a rescue situation, because the distressed person would not know from which direction a potential rescue might come, and hence where to aim the device. Based on these observations, signals with focused beams were predicted to perform well if the beam was oriented directly at an observer, yet perform poorly in other orientations. Those devices that did not exhibit this exaggerated angular dependence, but instead had a fairly uniform hemispherical illumination pattern, were predicted to perform better as a distress signal in situations where the location of a potential rescuer was not known.

- Effective Intensity. The effective intensity of the tested devices as calculated using the Modified Allard Method depended on both the peak intensity and the duration of the flash of a given signal. Within the group of 15 devices, flashtubes had the shortest duration flashes, the highest luminous intensities, and among the lowest effective intensities. The device utilizing an incandescent illuminant had the longest flash duration, but the low luminous intensity of this device limited its effective intensity, which was among the lowest measured effective intensities. The four LED devices had the highest effective intensities, even though their luminous intensities were much lower than the four flashtube devices. Three out of the four LED devices had effective intensities well above the rest of the group. Based on these lab tests, the LED-based signals were predicted to perform better than flashtube or incandescent signals, assuming optimal orientation of the directional devices.
- Intensity Profile. Devices with focused light outputs display large peak intensities in the center of the focal area, but the off-axis intensity of these signals drops precipitously. For example, device 18 has a peak intensity that dropped from approximately 75cd to almost zero within 15 degrees of its primary axis as shown in Figure 7. This trend was seen in both the horizontal and vertical orientations, suggesting that this device would need to be precisely aimed to be effective. Conversely, a signal with a more uniform hemispherical intensity profile, such as device 12 (Figure 8), would not need to be aimed at an observer to be seen. The intensity of this signal remains fairly uniform as it is rotated, suggesting that its ability to be detected would not be dependent on an individual's ability to effectively direct the focused beam towards an observer.
- Flash Consistency. For the 10 flash intensity profiles measured for each device, the output for the flashtube devices varied appreciably from flash to flash, whereas the LED flashes were consistent.

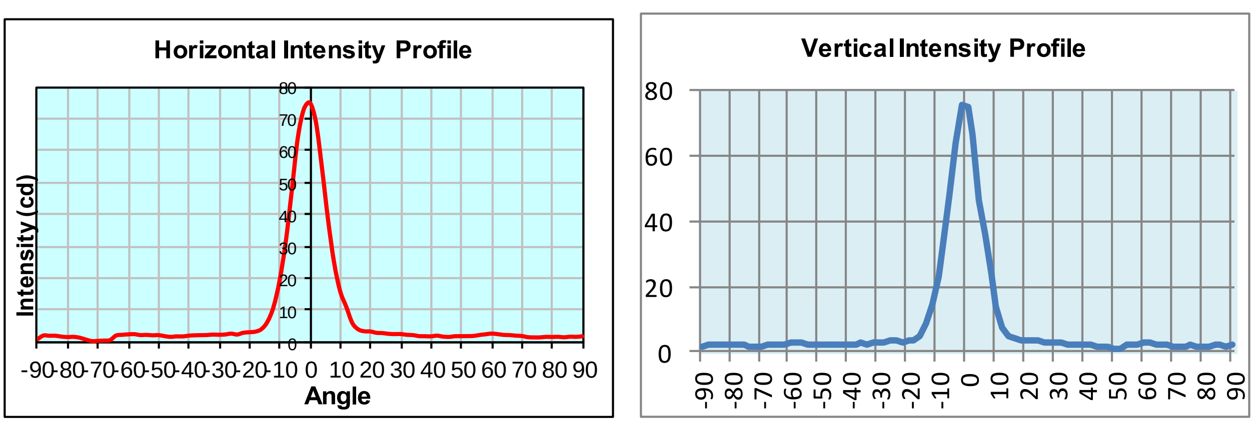

Figure 7. Focused beam device intensity profiles.

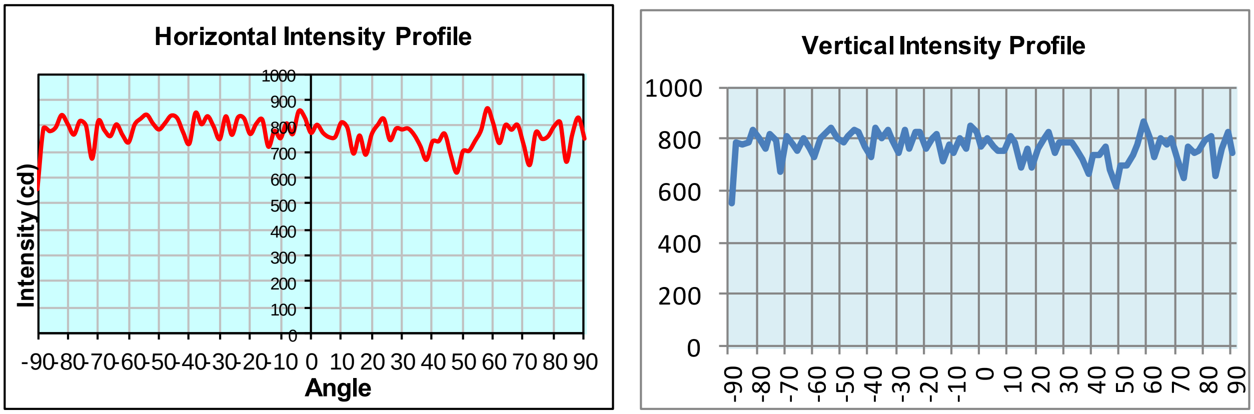

Figure 8. Hemispherical device intensity profiles.

3 INDIVIDUAL DEVICE DETECTABILITY TESTING

3.1 Individual Device: Selection

This testing was designed to evaluate the detectability and conspicuity of selected VDSDs in real-world night-time conditions, and assess any predictive relationship between the effectiveness of the devices as judged subjectively, compared with the effective intensity calculated from the lab data. The devices for this testing were selected based solely on their effective intensity. The top seven measured devices, as well as one device with a low effective intensity as a control, were chosen from the entire pool of devices tested in the lab to undergo further testing, see Table 1.

The testing was conducted to accomplish four objectives:

1. To begin sorting the devices from most effective to least effective, based on subjective ratings in two areas: detectability and conspicuity.
2. To gather additional qualitative data from the observers on preferred signal characteristics (e.g., color, flash rate, etc.) based on open-ended questions.
3. To identify any correlation between the “most effective” signals from field testing, and the measured effective intensities from lab testing.
4. To learn more about the practical effects of highly focused signal distribution patterns.

3.2 Individual Device: Methodology

Prior to device testing, a set of COIs was drafted to identify ratings and performance criteria of devices and explain the rationale behind each question. These COIs can be found in Appendix A. The COIs related to the field tests included:

- how easily a signal can be detected at night;
- whether a signal can be distinguished from background lighting;
- whether a signal can be distinguished from other light sources in the maritime environment;
- whether a signal is omni-directional (i.e., is the signal visible at different orientations).

Testing was conducted on 18 October 2011 in the vicinity of CG Station Point Judith, Narragansett RI, at approximately nautical twilight. Environmental test conditions were favorable to data collection and are described in greater detail below (Sec. 3.4.1). There were two test conditions: Test Condition One was conducted with a low level of background lighting with the test boat located to the south of the observer location with the open ocean in the background. This Test Condition focused on *detectability* of the signal. Test Condition Two was conducted with high-contrasting background lighting, with the test boat located to the northeast of the observer location with the Newport Bridge and shoreline as a backdrop. Test Condition Two focused on *conspicuity* of the signals. For both test conditions, shore-side observers were seated along a 50’ expanse of the easterly side of Station Point Judith in approximate position 41°21’41.84”N 71°28’49.84”W. Out of the eight devices tested, three devices were tested in multiple modes (different colors and/or flash rates), and two devices were tested in both a 45° and a 90° orientation due to their perceived directionality. Devices were energized from a 30’ test boat, and subjectively rated by observers on the shore at three different ranges, under two test conditions, and in the order shown below. The observers rated the devices as described in Section 3.4.

- Test Condition One (low level of background lighting):
  - 5 NM.
  - 2.5 NM.
  - 1 NM.
- Test Condition Two (high-contrast background lighting):
  - 1 NM (designated 1 NM-B).
  - 2.5 NM (designated 2.5 NM-B).
  - 5 NM (designated 5 NM-B) (tests initially planned but not conducted).

For Test Condition One, the signal devices were energized along an approximate line of bearing of 139°T from the observer position. For Test Condition Two, the observers looked along a line of bearing towards the Newport Bridge at approximately 040°T. Figure 9 and Figure 10, respectively, show the approximate boat positions for the two test conditions.

The testing was conducted with a team of military, civilian, and contractor personnel provided by the RDC, including 14 volunteer observers. A Test Director (TD) was located with the shore-side observers to oversee testing, assisted by Test Coordinators (TCs) located at the observer location as well as onboard the test boat.

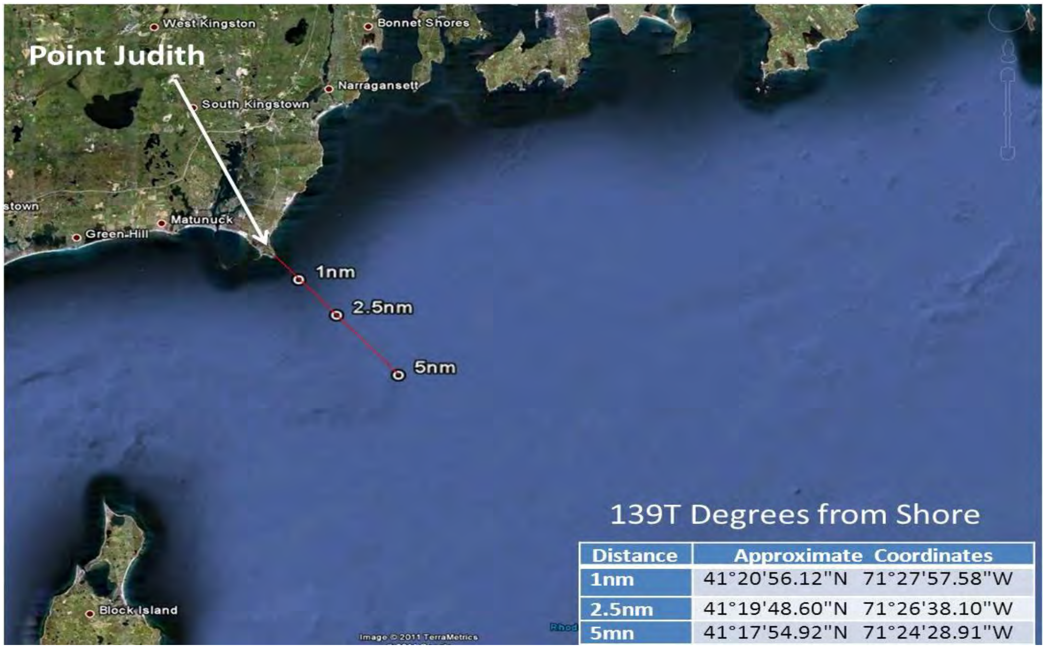

Figure 9. Test Condition One boat positions.

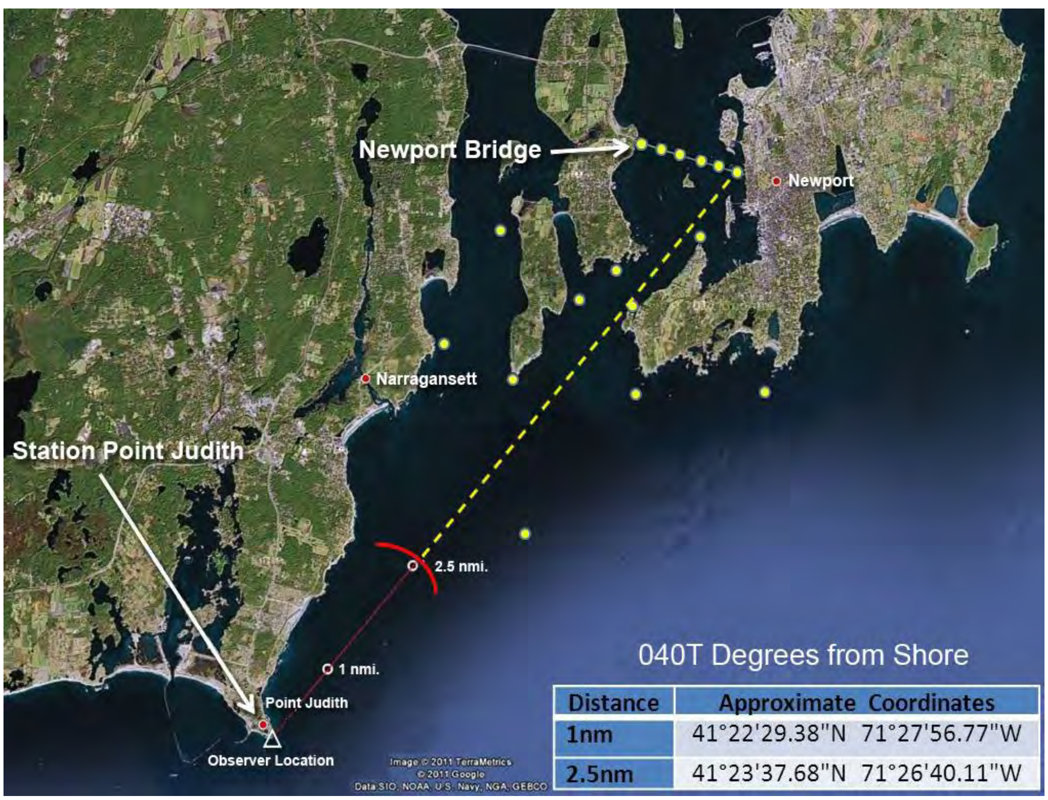

Figure 10. Test Condition Two boat positions.

3.3 Individual Device: Pre-Test Activities

Prior to the tests, the TD instructed the observers on the test process and distributed supplies needed to record observations. Each observer completed a Participant Background Information form (Appendix C) to indicate their previous experience with distress signals and to document any individual vision status that could affect performance (the observers' vision was not objectively evaluated for this study). Each background form was correlated to the survey forms by an observer identification number, so that observers could be linked to the data form without collecting personally identifiable information. Some anecdotal observer background information is noted below.

There were 14 observers: 12 men and two women. Men have statistically higher rates of color vision deficiencies than women (Howard Hughes Medical Journal, http://www.hhmi.org/senses/b130.html), and there were two male observers (Observers #6 and #11) who noted some form of green, to green/blue, color deficiency. These color deficiencies could have affected the ratings of those two observers who rated the blue and green LED devices lower than the average observer rating on most tests involving those colors.

Five of the observers had previous SAR experience dealing with locating visual distress signals used in an emergency situation. One of those five witnessed the signals from an aircraft from an approximate distance of 15 miles, while the other four had experience locating the signals from another vessel. The number of reported incidents per observer ranged from 1 to 10, so this sub-group had some prior experience sighting distress signals. A wide range of visibility (clear to foggy) and lighting (daylight to nighttime) was indicated for those prior incidents mentioned by the observers. Twelve of the observers reported that they had seen a signal flare used in a non-emergency situation. Six observers reported that they had interviewed or questioned someone about their sighting (or perceived sighting) of a distress signal.

The observers were provided approximately 30 minutes to fully acclimate their vision to the darkness, and they were provided flashlights and pens that were illuminated by red LEDs to record their observations (red light has a negligible effect on dark-adapted sensitivity). In addition, the observers were instructed to turn off any cell phones or other devices that might produce white light in the viewing area. Due to the length of time at the viewing site (about 2.5 hours), observers had access to a refuge equipped with red lighting to preserve night vision during breaks in the test process. Ambient lighting in the observer area was low, with readings from a Minolta "Illuminance Meter T-1H" indicating between 0.01 and 0.00 Lux. Point Judith Light (Light List Number (LLNR) 19450), located slightly to the right and behind the observers, had a noticeable white loom which, as the signal rotated, swept across the lawn to the side of the observers and on the breaking waves in front of them. It did not appear to have a negative impact on the observations, and no observer comments attributed difficulty associated with this light.

Immediately before the actual testing, the TD conducted three trial test events, instructing the boat to energize VDSDs, so that observers could become familiar with the survey forms and the test procedures. The trial tests also provided practice to the boat crew and the boat TCs in their roles, and established the flow of communications.

3.4 Individual Device: Testing

Figure 11 provides photos of the devices tested for this phase. Some of the devices were tested in more than one signal mode, and one device was tested in four different colors.

Figure 11. Devices tested in individual device testing.

The test team displayed the signals from the test boat, with the observers located on the station grounds. At the direction of the TD, the TC located on the boat energized the signal devices, one device at a time, following the test script for Test Condition One. The boat TC followed the test procedures detailed in Appendix D to ensure the devices were operated accurately and consistently according to the test script. For each test event, the TD informed the observers that the test had begun, and they were given time (approximately 2 minutes on average) to look for the device and record their observations on the survey forms prior to starting the next test event. Due to the anticipated difficulty of maintaining a steady direction of gaze in the nearly featureless test area (Test Condition One), the TD indicated the general direction for the observers to look for the devices. Periodically, the TD directed the boat to energize running lights so the observers could more easily align with the viewing area. The observers answered a series of three questions for each device test event, using the Likert scale shown in Table 2. Literature on "conspicuity" suggests that the three attributes captured in the observation aspects below are important to the detection of marine lights.

Table 2. Individual device testing Likert scale.

Test Series 1 Test Condition One – Tests at 5 NM – Low Level of Background Lighting					
Observation	**Not Visible**	**Disagree**	**Slightly Disagree**	**Slightly Agree**	**Agree**
	0	**1**	**2**	**3**	**4**
The device was easy to see.					
The device was attention-getting.					
The device was easily distinguished from other light sources.					

Test Condition Two (high-contrast background lighting) tests followed the same procedures as Test Condition One; however, some of the planned Test Condition Two tests were eliminated because even without background lighting, the range/device combinations proved very difficult for the observers to see. Under Test Condition One, 9 out of the 19 tests conducted at 2.5 NM were rated 0 (not visible) or 1 (strongly disagree) on the three visibility questions by more than half the observers. Because of this result,

it was recognized that they would not be seen with the decreased detectability of Test Condition Two. All of the Test Condition Two 5 NM-B tests and 9 out of 19 of the 2.5 NM-B tests were eliminated. Table 3 indicates which of the 2.5 NM-B tests were eliminated.

Table 3. List of 2.5 NM-B tests. The last nine tests were eliminated due to poor visibility in Test Condition One.

Test #	Name	Type	Device	Mode	Orientation
2B-18	Red	LED	20	Flashing Red	Vertical
2B-03	Red	LED	19	S-O-S	90° (on axis)
2B-07	White	LED	18	S-O-S	90° (on axis)
2B-06	White	LED	19	N/A	45°
2B-19	Red/White	LED	20	Flashing Red/White	Vertical
2B-16	Green	LED	16	Flashing	90° (on axis)
2B-17	White	LED	20	Flashing White	Vertical
2B-05	Red	LED	17	Flashing	90° (on axis)
2B-11	White	LED	13	N/A	45°
2B-09	White	LED	18	Flashing	90° (on axis)
~~2B-01~~	~~Blue~~	~~LED~~	~~15~~	~~Flashing~~	~~45°~~
~~2B-02~~	~~Blue~~	~~LED~~	~~15~~	~~Flashing~~	~~90° (on axis)~~
~~2B-04~~	~~Red~~	~~LED~~	~~17~~	~~Flashing~~	~~45°~~
~~2B-08~~	~~White~~	~~LED~~	~~18~~	~~Flashing~~	~~45°~~
~~2B-10~~	~~White~~	~~Flashtube~~	~~14~~	~~N/A~~	~~45°~~
~~2B-12~~	~~White~~	~~Flashtube~~	~~12~~	~~N/A~~	~~45°~~
~~2B-13~~	~~White~~	~~Incand.~~	~~4~~	~~N/A~~	~~90° (on axis)~~
~~2B-14~~	~~White~~	~~Flashtube~~	~~3~~	~~N/A~~	~~45°~~
~~2B-15~~	~~Green~~	~~LED~~	~~16~~	~~Flashing~~	~~45°~~

During the high-contrast background lighting tests, the TD coached the observers to find the device, as most found it very difficult to locate among the background lighting. There were several prominent lights in the background and the observers were told, for example, “the device is not the flashing green light.” Although the preference was not to aid the observers, coaching was provided as a better alternative to potentially receiving ratings on a light that was not part of the testing. Following the testing, observers were presented with four open-ended questions to provide an opportunity for them to describe a signal that they felt was more effective or less effective than the others, and to indicate what characteristics they felt were important in making that assessment. This provided some additional information for the test results, such as a preference for a particular characteristic of a signal as in Section 3.5.1.3, where observers expressed a color preference for a red signal. The post-testing questionnaire is provided in Appendix E.

3.4.1 Individual Device: Environmental Conditions

The evening of 18 October was relatively clear. Good visibility at the observer location was determined by identifying the entrance lights to Old Harbor on Block Island (Block Island Breakwater Light 3, LLNR 19720, and Block Island Breakwater Outer Basin Light 8, LLNR 19720), approximately 17 NM to the southwest, and the background lighting near the Newport Bridge, approximately 9 NM to the northeast. No rain showers were present on shore. The boat TC reported that the weather during the testing was clear with a short period of rain, with seas swells running generally 2’-4’ with occasional 5’-6’ swells towards the 5 NM test range. Recorded weather observations are provided in Appendix F.

3.5 Individual Device: Analysis and Conclusions

A three-step process was used to analyze the data. First, the data were arranged by observer rankings to facilitate review. Second, the total score assigned to each test (i.e., the sum of the Likert values for the three observations: easy to see, attention-getting, and easy to distinguish) was used to identify a group of high-performing devices; i.e., a group with high total scores, closely rated within the group, and numerically separated in the ratings from lower-rated tests. Third, the traits of this high performing group were reviewed to identify desirable characteristics for a non-pyrotechnic VDSD.

The "Ranked Results" worksheet, shown in Appendix G rearranges the data such that the highest average observer rating is shown first (left-most observer column); the second highest observer rating is shown next, and so on until the lowest average observer rating is shown last (to the right). The average observer rating is the sum of the marks assigned by all observers for the three questions rated during each test, divided by the number of marks that were entered for those questions. The tests are arranged such that within each series, the highest rated test event is shown in the first row, as calculated by summing the average test scores on each of the three survey questions for all 14 observers. Lower rated tests follow in the rows from top to bottom. Finally, the results were color-coded using automatic conditional green-yellow-red formatting in Microsoft® Office Excel® to assist in viewing the data. The data suggest two conclusions.

- With one exception, there is consistency within each test series in the ratings by the observers; i.e., the highest-rated tests received high ratings by all observers and the lowest-rated tests received low ratings from all observers. The exception is the 2.5 NM-B test series, where high and low ratings for the tests were mixed among the observers. This was the same test series where almost half of the tests were eliminated due to the difficulty in viewing the device signals. Even with the tests that remained in the series, which represented the better performing devices, observers demonstrated a relatively high level of difficulty seeing the devices against the background lighting, even with some coaching as described above.
- On average, there appeared to be little difference in the ratings for the three questions. Although one observer often marked high on the first question and low on questions two and three, asking any one of the survey questions on each device would have provided essentially the same result for the group as a whole; i.e., it would not have changed the rankings.

Observer data at the high and low ends were selectively eliminated to identify any potential outlier effect; i.e., whether eliminating that data from the analysis added or removed a device from the high performing group or the low performing group. This was done in three separate ways by removing:

1. the two highest rating observers (14 and 5), and the two lowest rating observers (11 and 3),
2. only the two highest rating observers (14 and 5), and
3. only the two lowest rating observers (11 and 3).

No differences in identifying the high and low groups were found after manipulating the data in this manner and all of the data were included in further analyses.

Next, the test series were arranged such that the tests in all series followed the sequence of tests (high to low total scores) established by the first (5 NM) series. This allowed the results of all five test series to be arranged from left to right, with the results on a particular row representing the same device test across all five series; see Table 3. This arrangement suggests several conclusions.

- The first four of the five test series (5 NM, 2.5 NM, 1 NM, and 1 NM-B) show generally consistent results among the top performing tests; i.e., highly rated devices in one series are highly rated in all series, and the ratings in general increase as the range decreases (i.e., the signals were easier to see at closer distances).
- The fifth series, 2.5 NM-B, is inconclusive because it is difficult to identify a high-rated group or determine an appreciable difference between the highest- and lowest-rated tests. All but one of the tests are rated low. One plausible explanation for this is that most of the observers had great difficulty in distinguishing the signals against shore lights at this range, and in some cases they were not certain that they were looking at the correct light among the background lights. As a result, this does not appear to be a good series from which to draw conclusions about desirable characteristics for non-pyrotechnic VDSDs, and will be excluded from further analysis. One conclusion that can be drawn from this series is that the devices are not very effective at 2.5 NM against high contrast background lighting.

Device tests were placed into perceived high-rated groupings in each test series based on the total score. In Table 4, the tests above the gray shading indicate the high group for each series. There were seven signals that appeared in the high-rated group in all four series. This group of seven (devices 18, 20 (three modes), 19, and 17 (two modes)) provides a starting point to look for desirable VDSD traits. As discussed previously, no high grouping is indicated for the 2.5 NM-B series.

Table 4. Summary of individual device test scores.

		5 NM				2.5 NM				1 NM				1 NM-B				2.5 NM-B			
		Average			Total	Average			Total	Average			Total	Average			Total	Average			Total
Test #	Device	1	2	3	1+2+3	1	2	3	1+2+3	1	2	3	1+2+3	1	2	3	1+2+3	1	2	3	1+2+3
5-09	19	3.7	3.8	3.8	11.3	3.9	3.9	3.9	11.7	4.0	3.9	3.9	11.9	3.9	3.9	3.7	11.6	2.1	2.0	1.6	5.6
5-18	20	3.7	3.6	3.4	10.6	3.9	3.5	3.5	10.9	3.9	3.6	3.4	10.9	3.8	3.3	3.0	10.1	2.9	2.6	2.4	8.0
5-19	20	3.4	3.1	3.2	9.7	3.6	3.4	3.3	10.4	4.0	3.6	3.6	11.3	3.6	3.4	3.1	10.1	1.9	1.7	1.6	5.2
5-12	17	3.2	3.0	2.9	9.1	3.9	3.6	3.4	11.0	3.8	3.5	3.5	10.8	4.0	3.6	3.5	11.1	2.3	2.0	1.7	6.0
5-17	20	2.9	2.9	2.9	8.7	3.3	3.0	3.1	9.4	3.9	3.6	3.6	11.0	3.7	3.4	3.1	10.2	1.3	1.3	1.0	3.6
5-10	17	2.6	2.6	2.9	8.1	3.7	3.9	3.7	11.3	3.8	3.9	3.7	11.4	3.7	3.6	3.6	11.0	1.3	1.1	1.2	3.6
5-06	18	2.6	2.5	2.7	7.8	3.4	3.6	3.8	10.8	3.9	3.9	3.8	11.5	3.5	3.5	3.3	10.3	0.5	0.6	0.4	1.5
5-08	18	2.0	1.8	2.4	6.1	3.9	3.7	3.9	11.6	3.6	3.2	3.4	10.3	3.8	3.4	3.4	10.6	2.3	1.9	1.6	5.8
5-15	16	1.6	1.9	1.7	5.2	3.5	3.7	3.7	10.9	3.9	4.0	3.9	11.9	3.6	3.9	3.6	11.1	1.7	1.6	1.5	4.9
5-13	15	1.6	1.7	1.6	4.9	1.7	1.6	1.6	4.9	3.4	3.4	3.5	10.3	2.2	2.6	2.3	7.1				
5-04	13	0.8	1.0	1.0	2.8	2.6	2.4	2.4	7.4	4.0	3.6	3.5	11.1	3.0	2.4	2.4	7.8	1.0	0.9	0.7	2.6
5-03	12	0.7	0.6	0.7	2.0	1.4	1.4	1.4	4.1	3.6	3.4	3.1	10.1	2.5	2.1	2.0	6.6				
5-14	15	0.4	0.4	0.4	1.1	0.1	0.1	0.1	0.2	1.2	1.0	1.0	3.2	0.0	0.0	0.0	0.0				
5-01	3	0.4	0.3	0.4	1.1	0.0	0.0	0.0	0.0	1.4	1.2	1.2	3.8	0.0	0.0	0.0	0.0				
5-11	17	0.4	0.3	0.4	1.1	0.6	0.4	0.5	1.6	1.7	1.8	1.9	5.4	1.3	1.3	1.2	3.8				
5-02	4	0.2	0.3	0.2	0.8	1.3	1.1	1.1	3.5	3.3	2.8	2.9	9.0	2.0	1.9	1.5	5.4				
5-05	14	0.2	0.3	0.2	0.7	0.2	0.1	0.1	0.5	2.1	2.3	2.2	6.6	1.1	1.0	0.9	3.0				
5-16	16	0.1	0.1	0.1	0.4	0.4	0.4	0.3	1.1	1.6	1.4	1.2	4.3	0.4	0.4	0.2	1.0				
5-07	18	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	1.6	1.6	1.5	4.7	0.5	0.4	0.3	1.2				

3.5.1 Individual Device: VDSD Characteristics

3.5.1.1 Individual Device: Effective Intensity

The strongest predictor of device effectiveness was effective intensity. As noted in Section 2, lab testing of the devices measured the intensity profiles of several of the devices, and the effective intensity of each was calculated. Because the temporal response of the eye makes short flashes of light appear much less intense to an observer, the *peak* measured intensities of the devices were *not* reliable predictors of effectiveness, based on the subjective observer ratings.

All of the flashtube devices had large peak intensities. However, their short-flash durations resulted in relatively small effective intensities, and the observers consistently rated these flashtube devices as not very effective. Conversely, the LED-based devices had much smaller peak intensities, but the extended duration of these flashes resulted in larger effective intensities, and the LED devices were consistently rated more effective. Specifically, devices 18, 19, and 20 were the three signals with the largest effective intensities calculated from lab measurements, and these devices ranked consistently amongst the best performing signals.

A comparison of the field data (Table 4) to the lab data (Table 1) showed that the calculations of luminous range predicted the relative distances at which the signals were clearly seen in the field test. For instance, the two devices which had the largest luminous ranges (19 and 20) routinely received the top marks in the field study. Subjective ratings under the low-background condition showed that these stimuli were clearly visible at 5 NM, which is a greater distance than the luminous range calculation predicted (3.25 NM). LED device 18 was clearly seen at 2.5 NM (the predicted luminous range) but also seen, with more difficulty, at 5 NM. LED Device 13 was clearly seen at 1 NM and seen with more difficulty at 2.5 NM; its predicted luminous range was 2.1 NM. The incandescent device (4) was clearly seen at 1 NM (its predicted luminous range), but not reliably seen at greater distances. The three flashtubes (Devices 3, 12, and 14) were not clearly seen at any of the tested ranges; their luminous range predictions were 0.25-0.75 NM. It appears that effective intensity and luminous range calculations are good predictors of the relative visibility of these signals.

3.5.1.2 Individual Device: Flash Rate

Observers who commented on flash rates identified a “faster” flash rate as being more effective, though none of the responses specified what rates would qualify as “fast.” This is consistent with the conspicuity literature (Laxar & Benoit, 1993): higher flash rates are more conspicuous. The highest flash rate in this study was 2 Hz (device 18). The literature would suggest that even greater conspicuity can be obtained with flash rates of 4 Hz. Faster flash rates were particularly effective at increasing conspicuity of low-contrast targets. In the marine environment, that should make it easier to see signals in fog or when there’s a lot of background lighting.

The observers also commented that the flash rate of some devices mimicked the slow flash of navigation aids or buoy lights, suggesting that a “fast” flash rate would need to have a higher frequency than typical navigational aids. Observer comments indicated that the more rapid flash rates better distinguished several of the devices from other environmental light sources. Because observer comments were made with reference to navigation aids, we interpret “lower” flash rates to be 1 Hz or below, and “higher” flash rates to be above 1 Hz for the purposes of this study.

For reference, U. S. AtoN flash characteristics are generally no faster than 1 Hz (quick flashing characteristic). AtoN systems internationally and within certain countries may employ AtoN flash characteristics faster than 1 Hz. For example, Canada's AtoN system uses cardinal buoys, which may exhibit a "very quick flash" characteristic of up 2 Hz. In addition, some signals prescribed for vessel use in the U.S. may exceed 1 Hz, such as the high intensity white light flashing used in Inland Waters and described above in Section 1.1.3. Flash rates for land-based lights should also be considered, as they often contribute to background lighting on the water. There are many factors to consider and the small amount of data collected in this testing highlights this as an area for further study.

3.5.1.3 Individual Device: Color

In our tests, most of the signals were white. Due to the nature of the flashtube output, all of the devices utilizing this illuminant technology were white. The availability of different color LEDs allowed different color illuminants to be presented in devices with identical physical designs; one device was available in white, red, green, and blue, and another was available in white or red, with a combined red/white flashing option.

No controls were made for the effective intensity differences among different color devices. Because the effective intensity of a device was the most important predictor of its performance, the intensity variability among the different colored signals is expected to influence their performance. Thus, the reported color preferences might not be representative of the most effective color for distress signals, but do qualitatively indicate the preference of the observers for certain colors of signals. These intensity differences notwithstanding, red was the most commonly identified color preference, though several observers noted that red signals were more easily confused with navigational aids.

The alternating white and red color mode of one device was identified by some observers as attention-getting, and by others as ineffective. Two observers reported that the alternating colors made the signal appear to shift location and one noted that this effect was "disorienting." Two observers noted that the alternating colors made the device "blend in" with a confusing background, making it more difficult to locate. Even so, the device (device 20) was ranked as high overall.

3.5.1.4 Individual Device: Beam Focus

Most of the tested devices were designed to produce a hemispherical illumination signal, though two devices produced a focused beam. The practical result of having a focused beam is to extend the visible range of a device if the beam is oriented directly at the observer. The visibility of the device, however, is severely limited for observers outside of the maximum illumination area (focused beam). The focused beam devices were tested in two orientations; one in which the most intense area of the focused illumination beam was directed at the observers, and one in which the focused beam was directed approximately 45° over the heads of the observers (off-axis orientation). When focused directly on the observers, the focused beam devices were among the best performing signals, though most observers were not able to see the devices in an off-axis orientation.

3.5.1.5 Individual Device: Flash Device Type

Three of the devices tested used a flashtube to produce an intense, short-duration flash. Although the peak intensities of the light output from these devices are much higher than for LED devices, the short duration of the flashtube output (3 to 21 microsecond (μsec) depending on the device; see Table 1) results in a lower effective intensity for these devices due to the physiological response time (temporal summation) of the retina. Because the visual system sums light within a 100 ms window of time, a longer, less intense light (e.g., from an LED) can be seen as brighter than the short, intense flash from a strobe or flashtube.

Observers rated all of the flashtube devices in the lower half of the group on each series, despite their large peak intensities. Within most of the test series, the performance of the devices mirrored the calculated effective intensity.

3.5.1.6 Individual Device: Flash Pattern

One device featured a flashing pattern that repeats "S-O-S" in Morse code; three short flashes, three long flashes, and three short flashes. Four observers specifically identified the S-O-S flash pattern as assisting in distinguishing the device as a distress signal, and only one observer specifically listed the S-O-S flash pattern as a characteristic that made devices less effective. One observer noted that varying the flash period was an effective attention-getting characteristic, but did not specifically mention that this "changing pattern" corresponded to an S-O-S message. Despite these responses, there was not a large difference in the observers' scoring of the devices during testing. Both the red and white signals scored similarly whether they displayed a regularly periodic flash, or an S-O-S flash. The S-O-S flash rate was relatively slow compared to flashing lights in general. This is because the emphasis on this traditional distress signal is placed on recognizing the length of the flashes as indicating alphabetical characters and not on attracting attention by means of a rapid flash rate. It is possible that if the S-O-S signal was presented at a faster flash rate, its changing pattern would make it more conspicuous; however, a faster flash rate might make it more difficult to identify as an S-O-S signal.

3.5.2 Individual Device: Conclusions

The highest-scoring devices were intense red or white LED-based signals with a moderate-to-rapid flash rate. All of the devices utilizing flashtubes or incandescent bulbs scored poorly, suggesting these illuminants are poor choices for electronic distress signals in their current implementations. Comparison of the results from the two orientations of devices 15, 16, 17, and 18 (the same device offered in four different signal colors) clearly demonstrates the limitation of a narrowly focused beam for omni-directional signaling. The effectiveness of devices with hemispherical illumination patterns suggests that good VDSD performance can be achieved without narrowly focusing the output beam of an LED array, and thus limiting its effectiveness to one direction. Finally, the observers' comments suggested the S-O-S flash pattern was an effective attention-getting characteristic, though the scoring of the devices did not indicate a large difference between S-O-S and periodic flash patterns.

Table 5 provides a summary of the relative effectiveness of VDSD characteristics suggested from this testing. Note: The table depicts those characteristics found in the tested devices: "more effective" traits are those common to the devices which scored best; and "less effective" traits are those common to the devices that scored worst. This does *not* represent rigorous findings from controlled studies on each characteristic; such studies should be considered in a follow-on project.

Table 5. Individual device: VDSD characteristics.

Characteristic	More Effective	Less Effective
Flash Rate	Faster ($\geq$ 1 Hz)	Slower (< 1 Hz)
Color	Red, White	Blue
Beam focus	Hemispherical	Narrow Beam
Flash device type	LED	Incandescent, Flashtube
Effective intensity	More Intense (> 10 cd)	Less Intense (< 5 cd)
Flash Pattern	S-O-S/Irregular	Regular

4 HEAD-TO-HEAD COMPARISON TESTING

Results from the individual device tests were used to develop a series of direct, "head-to-head," comparisons of pairs of electronic VDSDs, with the objective of investigating the effectiveness of certain attributes common to some of the devices.

4.1 Head-to-Head: Device Selection

The LED devices were selected for further evaluation during the comparative head-to-head testing based upon their superior performance in the individual testing. The selected LED devices were pitted against one another in a head-to-head comparison to determine which features would enable a device to be preferred over another by the observers. For comparison, the most-effective flashtube (Device 12) was also included. See Fig. 17 for the complete set of devices tested.

4.2 Head-to-Head: Methodology

Prior to device testing, a set of COIs was drafted to identify ratings and performance criteria of devices and explain the rationale behind the each question. These COIs can be found in Appendix A.

Testing was conducted on 9 November 2011 on land in the Groton/New London, CT area. Environmental test conditions were favorable to data collection and are described in greater detail below (Sec. 4.4.1). The testing was designed to compare two different signals in each test simultaneously, with the goal of selecting the more attention-getting signal, and identifying the characteristic(s) that most influenced the observer to select that signal. In each comparison, the pairs were constructed to compare devices for certain characteristics: intensity, color, and flash pattern. The tests were performed at two ranges: 1 NM and 2 NM. At the end of each test series (at the two ranges), tests were added that compared the "best white" signal and the "best color" signal against a traditional red flare, and also compared the flare to a "flash-bang" signal (described in Sec. 4.5.1.4).

For the 1 NM tests, the observers were located at the Mitchell College Bookstore, 437 Pequot Avenue, New London, CT. Observers stood near the eastern corner of a first floor deck. For the 2 NM tests, the observers relocated to Fort Trumbull in New London, and stood outside the walls on the south side of the fort. The devices were energized across the Thames River at Eastern Point Beach in Groton, CT for both series of tests. For the 1 NM tests, A and B devices were energized near the south corner of the parking lot. For the 2 NM tests, the location for the A and B devices was moved about 60 yards west to ensure the best viewing by the observers, with the change in viewing angle from the 1 NM to the 2 NM position. Figure 12 and Figure 13 show observer positions and the A and B device locations for the two series of tests, respectively.

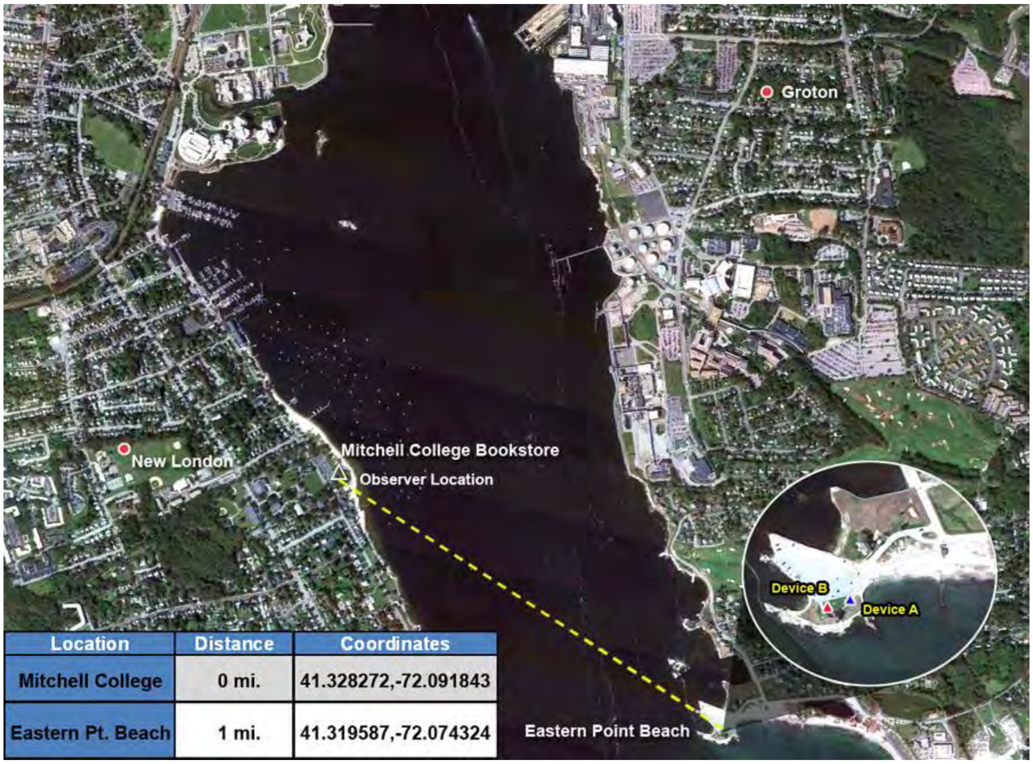

Figure 12. 1 NM head-to-head testing locations.

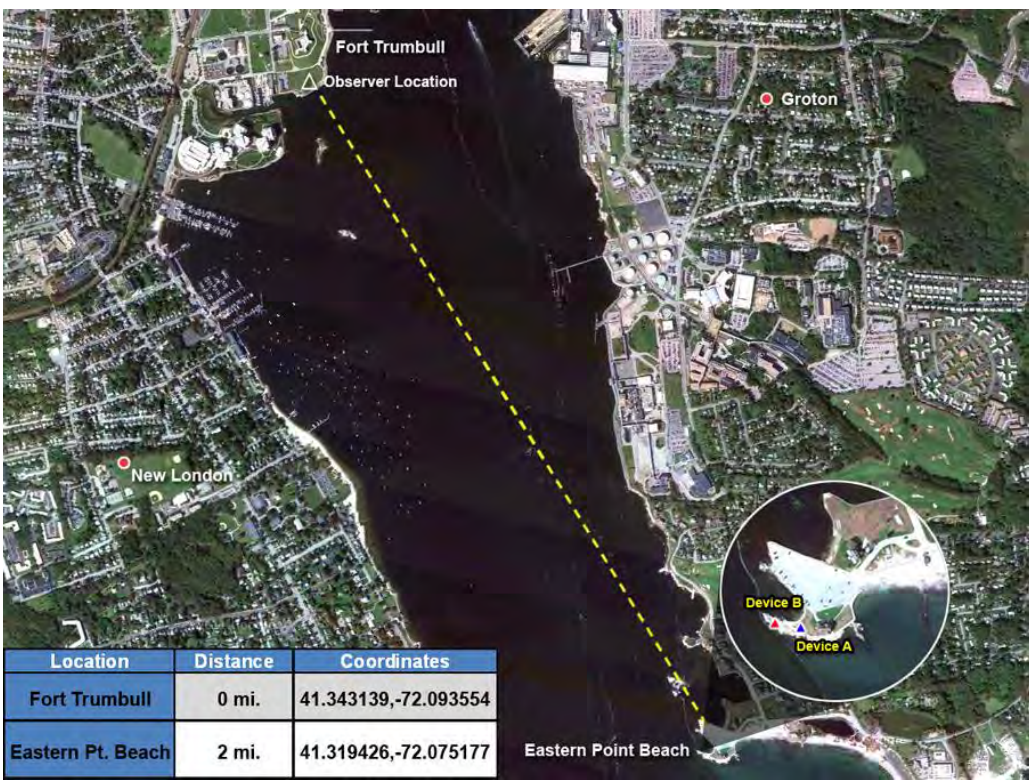

Figure 13. 2 NM head-to-head testing locations.

The testing was conducted with a team of military and civilian personnel from RDC, including 12 volunteer observers from RDC staff. A TD was located with the observers to oversee testing, assisted by TCs at the observer location as well as TCs who energized the devices at the Groton location.

4.3 Head-to-Head: Pre-Test Activities

Prior to the tests, the observers met at the RDC, where the TD provided supplies needed for the observers to record observations, and instructed the team on the test process. The observers departed for the first test location at Mitchell College, where each observer completed a Participant Background Information form (Appendix C) to indicate their previous experience with distress signals, and to document any individual vision status that could affect performance (the observers' vision was not objectively evaluated for this study). Each background form was correlated to the survey forms through the use of an observer identification number, so that observers could be linked to the data form without collecting personally identifiable information.

The observer group consisted of 12 respondents: seven male and five female. None of the observers in the group reported any color-vision deficiencies. Two observers (survey #10 and #12) reported previous SAR experience dealing with the locating of visual distress signals used in an emergency situation. Six of the 12 observers reported they had seen a signal flare used in a non-emergency situation. Only one observer (the observer with prior witnessing experience from a vessel) reported that they had interviewed or questioned someone about their sighting (or perceived sighting) of a distress signal.

Immediately before the actual testing, the TD conducted two trial tests so that observers could practice completing the survey forms, and become familiar with the test procedures. The trial tests also provided practice to TCs in energizing the paired devices, and established the flow of communications.

4.4 Head-to-Head: Testing

Figure 14 provides photos of the devices tested, with the exception of the flash-bang device that was added to the last series of tests (pyrotechnic comparison). Some of the devices were tested in more than one signal mode, and one device was tested in four different colors.

Testing began approximately at nautical twilight with the 1 NM series. The TCs energized the device pairs ("A" to the observers' left and "B" to the observers' right) simultaneously, at the direction of the TD, and each signal was presented approximately half the time from the "A" position and half the time from the "B" position. For test #7, the A/B comparison was made by alternating between two different modes of the same device, treating each mode as a separate device. Tests of color signals were interleaved with tests of white signals (i.e., testing was not divided into a white series and a color series). All focused devices were tested in an orientation such that the most intense illumination was directed toward the observers. A flashlight was energized towards the device TCs occasionally from the observer position to help the TCs locate the bearing for aiming the focused devices.

Observers filled out the survey for each test, indicating which of the two devices was more attention-getting, and which attribute(s) of four provided (intensity, flash rate, color, or other) was the most important factor(s) in choosing that device, with a comment field provided for open-ended observations. Figure 15 shows a sample of the observer survey form for one comparison test. Tests results were also indicated by a show of hands (for choosing signal "A" or "B") and entered in real time into Microsoft Office Excel to calculate which device was considered to be the most effective from each test grouping. These top performing devices were tested head-to-head against a handheld flare.

After completing the 1 NM test series, the observers moved to the Fort Trumbull location to begin the 2 NM series, using the same procedures.

Figure 14. Devices tested during head-to-head testing.

	Attention-Getting			Most Important Factor			
Test #	A	B		Intensity	Flash Rate	Color	Other
02							
	Comments						

Figure 15. Sample head-to-head testing survey form.

4.4.1 Head-to-Head: Environmental Conditions

There was good visibility for testing on the evening of 9 November as determined by a recorded visibility at Groton New London Airport (KGON). Visibility at this location was no less than 6 miles during the testing period, as compared to the greatest test range of 2 NM. Appendix H provides recorded weather observations.

4.4.2 Head-to-Head: Analysis and Conclusions

For each pair of stimuli presented, each observer chose the stimulus (A or B) that was more attention-getting. Data processing consisted of confirming that the real-time vote totals and those recorded on the survey forms were in agreement, and totaling the number of times a particular device characteristic was listed as being the “most important factor” in choosing one of the devices in a pair as more attention-getting. Because observers were allowed to choose more than one factor for each test, the total number of “most important factor” responses was not necessarily equal to the total number of votes cast for a particular device. If a specific factor was not indicated on the survey form, the “other” category was recorded.

The results were sorted into four categories: Flashing White Light Comparison (Table 6), Color Comparison (Table 7), Flash Pattern Comparison (Table 8), and Pyrotechnic Device Comparison (Table 9), according to the primary characteristic each test was intended to investigate. Each category is discussed below, followed by tabular results for that category. To facilitate comparison of tests between the same two devices at 1 NM and 2 NM, the results of these tests have been placed within the same table row in Table 6 through Table 9 below. In each figure, the vote totals for a preferred device equal the number of participants who preferred that device within a given test. The number of participants who preferred a particular characteristic is shown with ***IN*** indicating that a device was perceived to be more intense, ***FR*** indicating a preference for the flash rate of a given device, ***C*** indicating a preference for the color, and ***O*** indicating that "other" or no characteristics were identified as being superior.

4.4.3 Head-to-Head: VDSD Characteristics

4.4.3.1 Head-to-Head: Flashing White Light Comparison

A series of white flashing signals were compared to identify the impact of intensity and flash rate on the perceived effectiveness of the various devices. As was the case in the individual device testing, flashtube devices rated poorly, and the low perceived intensity of these devices was identified as being a shortcoming for flashtubes as a device category. In tests between devices 19 and 20, both very LED intense signals, device 19 was overwhelmingly preferred, and most of the observers identified the more rapid flash rate of this signal as the decisive criterion. Table 6 shows the flashing white light comparison.

4.4.3.2 Head-to-Head: Color Comparison

Red, white, blue, and green signals were compared in their flashing modes to evaluate observer preference for particular device colors. Though these signals share an identical physical design and have the same operational modes, the perceived intensity of the different color devices is not identical, and was not accounted for in these tests. Notwithstanding that limitation, these tests are representative of the performance of the devices currently available for testing.

The observers indicated a preference for the white signal over the blue, though the perceived intensity of the white device was the primary reason given rather than the color. In other comparison tests with the blue device, the red and green signals were preferred due to color and intensity. Similarly, the red signal was preferred over the white mainly due to color preference, though many observers noted the red signal appeared more intense at 2 NM. Observers indicated a preference for the intensity and color of the green signal over the white, though this preference was notably smaller at 2 NM than at 1 NM. Comparison of the red and green devices showed a clear preference for red. Table 7 shows the color comparison.

Table 6. Flashing white light comparison.

Color	Type	Device	Mode	Orientation	1 NM						2 NM					
					Test	Vote	IN	FR	C	O	Test	Vote	IN	FR	C	O
White	LED	20	White Flash	45	2	11	8	4	2	1	48	12	10	4	1	0
White	LED	13	N/A	45		1	0	1	0	0		0	0	0	0	0
White	LED	18	Flashing	90	3	1	1	1	0	0	47	1	1	1	0	0
White	LED	19	N/A	45		11	3	8	1	1		11	7	7	0	0
White	LED	20	White Flash	45	6	0	0	0	0	0	44	0	0	0	0	0
White	LED	18	Flashing	90		12	4	12	2	0		12	4	11	1	0
White	LED	13	N/A	45	8	11	5	5	0	3	42	11	6	3	0	2
White	flashtube	12	N/A	45		1	0	0	1	0		1	0	0	0	1
White	flashtube	12	N/A	45	9	0	0	0	0	0	41	0	0	0	0	0
White	LED	19	N/A	45		12	10	10	2	1		12	6	8	2	2
White	LED	19	N/A	45	11	12	10	8	1	0	39	12	8	7	0	1
White	LED	13	N/A	45		0	0	0	0	0		0	0	0	0	0
White	LED	13	N/A	45	13	0	0	0	0	0	37	0	0	0	0	0
White	LED	18	Flashing	90		12	6	12	1	0		12	8	10	1	2
White	flashtube	12	N/A	45	14	0	0	0	0	0	36	0	0	0	0	0
White	LED	20	White Flash	45		12	10	3	1	1		12	9	2	1	3
White	LED	19	N/A	45	16	12	4	11	1	0	34	11	2	9	0	1
White	LED	20	White Flash	45		0	0	0	0	0		1	0	1	0	0
White	LED	18	Flashing	90	20	12	8	9	0	0	30	12	8	7	0	2
White	flashtube	12	N/A	45		0	0	0	0	0		0	0	0	0	0

Table 7. Color comparison.

Color	Type	Device	Mode	Orient.	1 NM						2 NM					
					Test	Vote	IN	FR	C	O	Test	Vote	IN	FR	C	O
Red	LED	17	Flashing	90	5	9	4	6	9	0	45	10	2	3	9	0
Green	LED	16	Flashing	90		3	0	1	2	0		2	0	1	1	0
Blue	LED	15	Flashing	90	10	0	0	0	0	0	40	0	0	0	0	0
Green	LED	16	Flashing	90		12	5	10	5	0		12	5	6	5	1
White	LED	18	Flashing	90	15	12	8	4	2	2	35	12	5	4	3	2
Blue	LED	15	Flashing	90		0	0	0	0	0		0	0	0	0	0
Red	LED	17	Flashing	90	18	12	7	5	9	0	Test not conducted					
Blue	LED	15	Flashing	90		0	0	0	0	0						
White	LED	18	Flashing	90	21	1	0	0	1	1	29	0	0	0	0	0
Red	LED	17	Flashing	90		11	0	4	9	1		12	8	4	8	1
Green	LED	16	Flashing	90	22	12	8	1	5	1	28	7	5	1	1	1
White	LED	18	Flashing	90		0	0	0	0	0		5	1	0	1	3

4.4.3.3 Head-to-Head: Flash Pattern Comparison

Devices 15, 16, 17, and 18 (the same device in four different colors) offer an S-O-S Morse code flash pattern which was identified by several of the Individual Device Test observers as an attention-getting feature (see Section 3.5.1.6). To investigate this observation in a more controlled manner, two devices of the same color (device 18 (white) and device 16 (green)) were tested against each other while operating in a regular flashing mode and an S-O-S flashing mode. The results are included in Table 9. Observers indicated a strong preference for the white S-O-S flashing pattern vs. the white regular flashing pattern. The S-O-S flash pattern preference was also indicated for the same test with green signals (green S-O-S preferred over green periodic flash) at 2 NM, although the preference for the S-O-S signal was not as strong. There was no demonstrated preference, however, for either the green S-O-S or the green flash at the 1 NM.

There were eight additional trials in which the white S-O-S signal (device 18) was paired with other white flashing devices (see Table 8). An attempt was made to analyze those results to infer the potential value of the S-O-S flash pattern. However, it should be noted that the observers' score sheets only allowed them to score three distinct "attention-getting" factors: intensity, color, and flash rate. "Flash rate" technically refers to the slowness or rapidity of a series of flashes, not its pattern. Therefore, unless observers' specifically commented on the S-O-S pattern, we cannot be sure whether it was the flash rate or the flash pattern that contributed to the scores for device 18. A further investigation of flash rates and patterns would help to resolve this question.

When tested against devices with a regular periodic flash pattern, a preference for the white S-O-S device was clearly observed in six of the eight pairings with other devices. Interestingly, the comments from several respondents indicated that they did not recognize the flash pattern as signaling S-O-S. Because Morse code may not be readily recognized by some participants in a distress situation, this finding is especially noteworthy as it indicates that the irregularity of the flash pattern is an attention-getting feature independent of the message intended to be conveyed. Table 8 shows the flash pattern comparison.

Table 8. Flash pattern comparison.

Color	Type	Device	Mode	Orient.	1 NM						2 NM					
					Test	Vote	IN	FR	C	O	Test	Vote	IN	FR	C	O
Green	LED	16	S-O-S	90	1	6	2	5	1	0	27	9	7	4	1	1
Green	LED	16	Flashing	90		6	1	6	1	0		3	0	3	0	0
White	LED	20	S-O-S	90	7	12	11	3	1	2	38	10	6	6	1	2
White	LED	20	White Flash	45		0	0	0	0	0		2	0	2	0	0
White	LED	18	S-O-S	90	12	9	6	4	0	0	Test not conducted					
White	LED	20	White Flash	45		3	1	3	0	0						
White	LED	18	Flashing	90	17	1	0	1	0	0	33	0	0	0	0	0
White	LED	18	S-O-S	90		11	9	7	0	1		12	9	5	1	2
White	LED	19	N/A	45	19	7	0	7	0	0	31	12	7	9	2	0
White	LED	18	S-O-S	90		5	0	4	0	1		0	0	0	0	0
White	flashtube	12	N/A	45	4	0	0	0	0	0	46	0	0	0	0	0
White	LED	18	S-O-S	90		12	11	7	1	1		12	9	4	0	2
White	LED	18	S-O-S	90	Test not conducted						43	12	11	9	1	1
White	LED	13	N/A	45								0	0	0	0	0

4.4.3.4 Head-to-Head: Pyrotechnic Device Comparison

Four electronic devices, expected to be the most effective based on previous tests, were tested head-to-head with a standard red flare used by mariners, to provide a direct comparison between what is generally regarded as the most effective VDSD, with the best non-pyrotechnic alternatives available in this study. Two of these devices had been tested earlier in the head-to-head tests: device 19, the "best" white signal, and device 17, the "best" color signal (red). The third electronic signal tested against the flare was device 20 in "flicker" mode. This device was included because it had a unique flash pattern (rapid alternating red/white flash pattern) and a high effective intensity. Data from prior testing suggests that this combination of flash characteristic and effective intensity would enhance conspicuity (this device also has a white flash mode, a red flash mode and an alternating red/white flash mode, which is slower than the flicker mode). The fourth electronic device was an experimental "flash-bang" device. The Non-Pyrotechnic Flash Bang (NPFG) is an experimental device designed to be used in law enforcement to distract and disorient. It produces extremely intense light and sound fields. For these tests, the sound was disabled. The NPFG uses proprietary technologies that overdrive the LEDs to produce light intensity much greater than is attainable by conventional methods in a small package. Although the NPFG was not received prior to the "Individual

Device Detectability" testing, it was included in the “Head-to-Head” testing to illustrate the kinds of intensities that are possible in an LED device, and to see how it compared to the other devices.

In the comparison of device 19 (white) and device 17 (red) to flares, a majority of the observers preferred the pyrotechnic signals due to their much higher intensity, though several observers in each test noted the flashing of the electronic signal was more attention-getting. Also notable was that four observers indicated the red color of the flare was more attention-getting than the white color of device 19. No observers indicated a preference for a white-colored signal during this test.

Device 20 in red flicker mode was preferred over the flare by eight of the 12 observers at both 1 and 2 NM. This was true even though all of the observers who preferred the flare thought it was more intense than device 20, and none of those who preferred the electronic signal thought it was more intense than the flare. This result is especially interesting because it is the only instance in which a majority of the observers preferred a distinctly less intense signal over a more intense signal. Table 9 shows the pyrotechnic device comparison. Device 20's unique flicker flash rate was noted by most observers as what made this device more attention-getting than the flare. Based on the survey results, it was not clear whether the flicker speed or flash pattern was responsible for the effectiveness of this device.

Table 9. Pyrotechnic device comparison.

Color	Type	Device	Mode	Orient.	1 NM						2 NM					
					Test	Vote	IN	FR	C	O	Test	Vote	IN	FR	C	O
White	LED	19	N/A	45	23	4	0	4	0	0	49	3	0	3	0	0
Red	Flare	Flare	N/A	45		8	7	0	4	0		9	8	0	4	0
Red	LED	17	Flashing	90	24	2	0	2	0	0	50	2	0	2	0	0
Red	Flare	Flare	N/A	45		10	10	0	3	1		10	8	2	2	0
Red	Flare	Flare	N/A	45	25	4	4	0	2	0	51	4	4	0	1	0
Red	LED	20	Red Flicker	45		8	0	7	0	1		8	0	6	0	2
Red	Flare	Flare	N/A	45	26	1	1	1	1	0	52	2	1	2	1	0
Flash Bang	Flash Bang	Flash Bang	N/A	90		11	6	10	1	1		10	3	7	2	2

4.4.4 Head-to-Head: Conclusions

The results of head-to-head device testing are consistent with many of the conclusions drawn from individual device testing: intense red and white signals with a faster flash rate (“faster” considered to be greater than 1 Hz in this study) were typically preferred, and device using a flashtube was not (the incandescent bulb device was not included in head-to-head testing). The effectiveness of an S-O-S flash pattern at distinguishing a distress signal from navigational aids was the reason some observers preferred this pattern over a flash with a regularly periodicity, even by observers who did not recognize the Morse code S-O-S message. The importance of the flash pattern of a distress signal was further demonstrated by the effectiveness of the red flicker mode of Device 20 when compared to a pyrotechnic flare. As was previously noted, this was the only example of a head-to-head comparison in which a distinctly more intense signal (the flare) was not preferred by a majority of the observers.

Comparisons between different color signals of the same device showed the red signal to be the most preferred, followed by the green, white, and blue. A preference for a red signal was indicated in the one other color comparison test. In this test, white device 19 was compared to the red flare. Thus, when observers indicated a preference, red signals were consistently preferred over other colors of distress signals throughout the head-to-head testing. The lack of effective compensation for intensity differences between different color devices makes further extrapolation difficult regarding the relative effectiveness of green, white, and blue colored signals.

Table 10 provides a summary of the relative effectiveness of VDSD characteristics suggested from this testing.

Table 10. Head-to-head: VDSD characteristics.

Characteristic	More Effective	Less Effective
Flash Rate	Faster (> 1 Hz)	Slower (≤ 1 Hz)
Color	Red	Blue
Flash Device Type	LED	Incandescent/Flashtube
Effective Intensity	More Intense (> 10 cd)	Less Intense (< 5 cd)
Flash Pattern	S-O-S, Irregular	Regular

5 ERGONOMIC TESTING

5.1 Ergonomics: Methodology

This testing was designed to study desirable VDSD characteristics unrelated to signal performance, and considered such aspects as ergonomics, durability, storage, and maintenance under a prescribed scenario. The scenario involved a vessel in distress, 10 miles or more from land, at night, and potentially in cold air/water temperatures. The user (person in distress who uses a distress signaling device) could be experiencing reduced dexterity due to cold hands, or could be wearing gloves. The user purchased the distress device but has not used it or become familiar with it, establishing a premium for an easy-to-use, intuitive device. Rescuers have been notified of the distress, but have only a general location for the distress vessel. Rescuers are in the LOCATE phase of the SAR evolution. The user does not know from which direction rescuers would be approaching.

Based on this scenario, and building upon observations from the March 2011 VDSD Functional Requirements Workshop (U.S. Coast Guard Research & Development Center, 29-30 March 2011), COIs were developed. The criteria contained in the COIs were tested using a combination of methods: a usability survey taken by volunteer participants, and an ergonomic standard evaluation conducted by SMEs. Appendix A contains a list of COIs that were used to develop the tests and survey questions involved in the ergonomic testing.

Usability data from the panel of participants was obtained during testing in Mystic, CT on 22 November 2011. The participants examined the devices indoors under simulated nighttime lighting conditions, and were asked to rate various ease of use aspects. Data was obtained by examination of the devices by SMEs in two office locations; Mystic, CT and Beavercreek, OH. On 28 November 2011, the SME at Mystic performed drop, float, and water submersion tests, and measured weight, as well as the time to initiate a flash. The SME at Beavercreek used the above SME data to complete an evaluation of the devices against a set of accepted ergonomic standards on 1-3 December 2011.

5.2 Ergonomics: Testing

Figure 16 provides photos of the 14 devices tested in this phase.

5.2.1 Ergonomics: Usability Testing

Prior to this testing, the TD designed the test area so that consistent lighting conditions to simulate a dimly lit nighttime environment would be present for all the participants. The 14 devices were separated into three sets (two sets of five, one set of four) so that three participants could run through the testing simultaneously.

For test purposes, the device numbers are presented as X-Y, where X indicates the set, and Y is the device number within that set. For analysis in this report, however, the device numbers were converted such that they remain consistent for each phase of the testing. The participants completed a Participant Background Information form to indicate their previous experience with distress signals, and to document any individual vision status that could affect performance (the participant's vision was not objectively evaluated for this study). This background form was placed at the beginning of the survey form, so that the background information could be correlated to the survey data without collecting personally identifiable information. Testing began after the participants had completed the background information, received a briefing concerning the purpose of the testing, and acclimated to the low lighting conditions (20 minutes). Table 11 provides participant information.

Test conditions included an ambient temperature of 70 °F (indoor conference room) and low lighting conditions measured at 10 lux. The participants were asked to answer a series of questions about each device while operating it according to the survey instructions, the overall objective being to discover how intuitive and easy the participants felt the devices were to operate. Participants rated each device on a five-point Likert scale, as shown in Table 12. Appendix I provides the entire survey for one device.

Participants were also asked to indicate how they would hold the device to properly attract attention, choosing among several options (drawings). For some of the tests, the participants wore gloves to simulate reduced dexterity that might result from having cold hands. Background information on this practice is provided in Appendix J. The glove used for testing was a widely available work glove made from heavy duty cowhide leather (Figure 17). Three participants went through the testing at once, one at each station of devices.

Figure 16. Devices ergonomically tested.

Table 11. Ergonomics: testing participants.

Previously Used a VDSD	Gender	Difficulty Seeing at Night
No: 9 Yes: 0	Male: 8 Female: 1	No: 8 Yes: 1

Table 12. Sample questions for ergonomic testing.

Set One	Device 1	Device 2	Device 3	Device 4	Device 5
ID Number					
Activate Device	Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree				
The device was easy to activate.					
I could have activated the device without reading the instructions; operation was obvious.					
The "on" switch was located in an obvious location.					
I was able to activate the device quickly.					
The device operation instructions were clear and concise.					

Figure 17. Gloves used to simulate cold hands.

On 28 November 2011, a series of measurements were recorded for each device by the SME at Mystic, CT, including the weight of the device and the time delay between turning the device on and first seeing illumination. A drop test, a float test, and a water immersion test were also conducted on each device. The drop test was done from a height of 8' onto a concrete surface. The device was given a score of 0 if it failed to function after the drop or a 1 if the device still functioned after test. A score of 0 was given to the device if it did not float in water and a 1 if it did float. The device was immersed in 1 foot of water without manipulating the device controls and given a rating of 0 if it did not operate after 30 seconds and a 1 if it did. Table 13 shows these results.

Table 13. Ergonomic test results.

Criteria	Device													
	4	10	6	8	20	7	1	12	14	13	11	18	19	9
Drop (0: not function, 1: function)	1	1	1	1	Not tested	1	0	1	1	1	1	1	1	1
Float (0: no, 1: yes)	0	0	0	1		0	0	0	0	0	0	0	0	0
Immersion (0: no, 1: yes)	1	1	1	1		1	0	1	1	1	1	1	1	1
Total Value	2	2	2	3		2	0	2	2	2	2	2	2	2

Additional data, the procedures followed, and the associated environmental conditions are provided in Appendix K.

5.2.2 Ergonomics: Standards Evaluation

As standards were not found for non-pyrotechnic VDSDs, the criteria used to evaluate the devices included a combination of pyrotechnic visual distress device standards as documented by Kroemer and Marras (1980), characteristics discussed in the VDSD Functional Requirements Workshop (U.S. Coast Guard Research & Development Center, 29-30 March 2011), and ergonomic standard used for handheld tools (Cacha, 1999). These included metrics for instructions, storage, durability, and physical attributes, as described below.

- Instructions to Energize and for Proper Use. Instructions should be:
  - Clear and concise, providing only information needed.
  - Readable in low light levels (luminance not more than 0.01 ft L, 0.03 cd/m2).
- Character height should be at least 0.4 cm for reading under low level luminance, and in high contrast colors.
- Storage. Distress devices are often stored on a vessel without being used for long periods of time. Characteristics that will help ensure it is functional when needed include: easily identifying the device as a distress device, preventing self-activation through good design, and providing expiration information. A device can be inadvertently activated while stored, and deplete battery capacity available for an emergency event. One device was activated during transport and spent several days energized by the time of receipt. Use of less common batteries such as a CR 123, instead of common electronic batteries such as AAs or AAAs, may also be recommended so that it is less likely that the batteries may be borrowed temporarily for other uses and then put back into the device in a partially discharged state.
- Durability. The durability of the device was determined by a single drop test, a water immersion test, a float test, as described above in Section 5.2.1.
- Weight/Configuration. The device may need to be held by hand for a long period of time in a deployed position, putting a premium on low weight and easy to hold characteristics. The device was examined to determine the user’s ability to hold it securely with a tactile handle or to secure it to a personal floatation device (PFD) or other type of personal protective equipment (PPE).

5.3 Ergonomics: Analysis and Conclusions

The devices analyzed in this study came in many shapes and sizes, and the large array of features made it difficult for the participants to compare the devices with one another. For example, several devices were meant to attach to a PFD and others were meant to be held by hand, but all were rated for ease of holding in

a deployed position. One device was water-activated, while the others used various types of mechanical switches to activate the signal.

Table 14 presents the overall numeric results of ergonomic testing. All color-coded questions were rated on the 5-point Likert scale. An average rating is provided for each device on each of the six participant rating factors (highlighted in yellow). Those six average ratings were totaled for each device and used to order the device results, with the highest device ratings total on the left, and decreasing totals in the columns moving to the right. The average device ratings were color-coded using automatic conditional green-yellow-red formatting in Microsoft Office Excel to assist in viewing the data. "Correct deployment" indicates the percentage of participants who selected the correct figure drawing when asked how they would deploy the device to best attract the attention of a rescuer. "Favorite overall" indicates the number of participant votes for each device.

Table 14. Ergonomics test results.

	DEVICE													
PARTICIPANT Ratings	11	1	8	19	12	10	14	7	9	13	20	18	6	4
1. Easy to energize	3.8	3.8	3.2	3.4	3.5	3.3	3.9	3.0	2.9	2.9	3.2	2.6	2.0	1.2
2. Easy to use	4.8	4.6	4.2	4.3	4.2	4.3	4.4	3.9	3.8	4.0	3.8	3.2	2.9	3.6
3. Weight and configuration	4.1	3.6	4.0	3.6	3.5	4.3	3.7	3.6	3.4	3.6	2.2	3.9	3.6	3.7
4. Reduced dexterity	4.8	4.4	4.0	4.3	4.5	3.0	3.3	3.6	3.3	3.3	3.4	3.0	2.7	1.4
5. ID as distress signal	4.6	3.9	4.4	3.7	3.6	4.2	4.0	3.9	4.1	3.6	4.4	3.3	3.9	2.3
6. Function as expected	4.6	4.7	4.3	4.6	4.5	4.5	4.1	4.1	4.2	4.1	4.2	4.4	4.0	2.8
	26.7	25.0	24.1	23.9	23.8	23.6	23.4	22.1	21.7	21.5	21.2	20.4	19.1	15.0
Correct deployment	67%	78%	89%	78%	67%	78%	88%	78%	50%	78%	11%	56%	78%	50%
Favorite overall	3	1				2	1	1	1					

	DEVICE													
SME Ratings	11	1	8	19	12	10	14	7	9	13	20	18	6	4
1. Ergonomic standards	2.8	3.9	2.2	4.0	4.4	2.4	2.2	3.9	2.2	1.4	4.6	1.2	2.2	1.4
2. Inadvertantly activate	3.0	5.0	2.0	1.0	1.0	4.0	3.0	5.0	4.0	5.0	5.0	5.0	2.0	5.0
3. Durability	2.0	0.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		2.0	2.0	2.0
4. Storage requirements	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Ratings Total	7.8	8.9	7.2	7.0	7.4	8.4	7.2	10.9	8.2	8.4	9.6	8.2	6.2	8.4

Device 11 was the participants' overall favorite, although numerically (ratings total) there was not a large difference between several highly rated devices. Device 11 had a unique switching mechanism, whereby the switch slid on a metal piece that provided positive tactile feel. The second overall favorite as selected by the participants was device 10, although the sum of the participant ratings would have put it in sixth place. Given that this device used the same exterior as 9 in a housing different color, it is interesting to note that device 9 received slightly lower participant ratings.

These two favorite devices (11 and 10) were unable to deliver a complete set of characteristics that the users desired for the scenario. For example, device 10 only scored a 3 for use with reduced dexterity and neither device scored over a 4 for "Ease to energize." Both devices (11 and 10), however, could be easily improved in terms of ergonomics with some minor changes, such as better directions for activation and deployment. Given the scenario in this study, some devices with unique features, such as device 4 which is water activated, did not rate very well. Another interesting feature was found on device 6. It appears to be a one-time use device because it is activated by removing a tab from the body and, once activated, there is no method provided to store the tab once it is pulled. Even in an office environment, the tab was not easy to reinsert using bare hands. That feature (re-use) was not applicable to the scenario because there was no requirement for a device to have repeated on/off capability.

In a distress situation, tethering the device to the user is an important feature. One user commented that a Velcro® strap provided for one device should be longer so the device could be mounted on their head. Users liked the dual functionality of having a flashlight with the strobe feature on some of the devices. Though this may appear to be a convenient feature, having dual functions may incline the user to use the device in a non-distress situation, and could reduce the battery capacity available for an emergency event.

Several features that made a device more usable and ergonomic within the defined scenario were noted in this study, based on participant observations, expert evaluation, and ergonomic best practices. Table 15 summarizes some of the desirable VDSD characteristics and lists the devices used in this test that displayed similar features.

Table 15. Ergonomics: device characteristics.

Feature	Best Practice	Device(s) with this Feature
Color	Orange color if bright or florescent or yellow to signify a distress device.	1, 7
Tethering	Provide several options to mount device (wrist, Velcro, or clip) or as a user suggested, a head mount. Ensure mounting techniques do not interfere with activation and can be done with limited dexterity.	7, 13
Weight	Light weight. Users seemed to prefer weights around 4-5 oz.	7, 10, 11, 13, 18
Activation	Activate like a flashlight, either pushbutton or switch. Twist activations were not favored.	1, 12, 11, 14, 19
Quick illumination time	Users want to know device is working right away. A time of 1.5 seconds felt too slow.	12
Instructions for activation and deployment	Instructions can be symbols or text but must be readable in low light (white on black). Users were not always accurate with their deployment choices so deployment instructions are critical.	20
Grip	Comfortable grip within ergonomic standards.	6, 9, 10, 14
Tactile features	Tactile button, switches, and handle are critical to activation with gloves, wet hands, etc.	7, 12, 19
Expiration date	Providing an indication of battery strength or duration of battery life would assist users with maintaining device.	6
One function with unique battery	To ensure device is only used for emergency so battery will be at best capacity, device should only have one mode. Batteries are preferred that cannot be used to any other purpose.	4, 6, 10, 18, 19

6 OVERALL CONCLUSIONS

6.1 Insights Gained

In this study, a large number of features affecting both the signal characteristic and ergonomic design were examined, and much of this report focuses on the quest to discover which of these individual features may contribute to increasing the effectiveness of a VDSD alternative to flares. Following this path, individual tradeoffs would presumably be made to conceptually design a highly effective device. While recognizing the value of this approach, it is worth considering a larger tradeoff between advanced technology and simplicity for the user.

For example, a dual coverage signal (omni-directional and focused beam) feature appears very useful. It would allow the mariner to visually signal distress through 360° when the distressed person does not know from which direction a rescue unit might arrive, and it would also provide a more powerful signal to be aimed to attract attention when there is a logical direction in which to aim. The downside of such a device is that it could be sufficiently confusing that an untrained person might not use either feature effectively.

The same can be said for a device that has several different signal modes or flash patterns, but takes some familiarity or training to use. Contrast that with a VDSD that simply has an "on" switch and needs only to be held over the head to deploy properly. The disadvantage of this device is that other very useful features are not present, but the advantage of this device is an increased probability that it will be used at the high end of its effectiveness, somewhat diminished by the absence of some features. Along those lines; despite the many disadvantages of flares, a big advantage is that they are simple, and generally all operate in the same way.

This line of thinking does not suggest a one-size-fits-all simple device approach. It may make sense to have several levels of devices; a simple relatively foolproof device for the recreational boater, a more sophisticated device for charter boats and similar commerce, and a technologically superior device for large vessels. Each device would have a commensurate cost, training, and perhaps maintenance load, and could be mandated according to the level of hazard represented by the maritime activity, and/or selected by the desires and requirements of the mariner. The benefit of this approach is that each device within its class could be made to operate in the same manner. Today, the plethora of devices creates a unique experience each time a new device is encountered: how to energize, how to aim, how to store, etc. A set of common features presented within several standard classes of devices, targeted for the appropriate user, might increase the probability that all three classes would be used more effectively. Conclusions on specific VDSD characteristics are discussed below.

6.1.1 Signal Testing

Visibility testing consisting of individual device testing (for conspicuity) and head-to-head comparison testing (for attention-getting) produced consistent results; the most effective VDSDs were intense red or white LED-based signals, with a moderate to rapid flash rate.

- Effective Intensity. Analysis of the data for white signal lights showed that the most effective VDSDs had, in addition to other key attributes, the highest effective intensities. This suggests that lab tests, where effective intensity is calculated from quantitative measurements of peak intensity and flash duration, may be used in place of field tests to estimate the range at which devices can be detected. Table 16 compares metrics for eight devices tested in the lab, with their predicted luminous range and relative field test ratings. The top three devices stand out from the rest; they have a high effective intensity and were calculated to have the greatest luminous range. These three devices received the highest average field test ratings as well. Reinforcing the notion that effective intensity as measured in the lab is a significant indicator of how well VDSD signals will perform in real world over-the-water environments under given meteorological conditions. Peak intensities, on the other hand, were not good predictors of observer ratings. This is the primary reason why in the field testing, LED devices excelled, while short-duration/high-peak intensity flashtube devices performed poorly.

Table 16. Effective intensity: lab testing vs. field testing.

Device	Type	Peak Intensity (cd)	Effective Intensity (cd)	Luminous Range (NM)	Average Field Test Rating for Individual Device
19	LED	81	22.4	3-3.25	11.6
20	LED	109	21.0	3-3.25	9.8
18	LED	86	17.0	2.5-3	10.1
13	LED	9.9	3.57	2.10	7.3
4	Incandescent	1.2	1.16	1.00	4.7
12	Flashtube	22,171	0.58	0.75	1.2
14	Flashtube	1,471	0.177	0.40	2.7
3	Flashtube	536	0.056	0.25	5.7

- Flash rate/pattern. Faster flash rates are more effective in attracting attention, but with red, white, or green signal colors, flash rates that are close to commonly used navigation aids may be confused with them. For this study, "faster" flash rates were considered to be faster than 1 Hz, as explained in Section 3.5.1.2. Observer comments suggest that a distinctive/irregular flash pattern is more effective; however, the results were inconclusive as only one such device was tested (Morse code S-O-S flash pattern).
- Color. Although a preference was evident for color signals, the impact on the effectiveness presented by color signals is inconclusive, as no controls were used in this study for the effective intensity differences between different colored devices. Most often, red was the color of preference, although this may lead to confusion with navigational aids. Blue was rated poorly. Signals with alternating colors may have promise as effective VDSDs; however, results in this area were inconclusive. Only one alternating signal (red and white) was tested, and there were pro and con observations on that device.
- Beam Focus. Devices that produced a focused beam were very effective when aimed properly. The disadvantages of these devices are: (1) most observers were not able to see the devices in an off-axis orientation, and (2) the persons in distress, according to the LOCATE scenario used, would not know in which direction to aim the device. There may be potential in investigating a dual-focus device to serve both a 360° signal when the direction of potential rescuers is not known, and a focused signal that can provide a more intense signal when aimed purposefully.
- Pyrotechnics Comparison. Comparisons of a pyrotechnic flare to non-pyrotechnic VDSDs suggest that, while the flare is more intense, an equally effective or superior electronic VDSD design may indeed be achievable.

Table 17 provides a summary of the relative effectiveness of VDSD signal characteristics suggested from this study.

Table 17. Summary of relative effectiveness of VDSD characteristics.

Characteristic	More Effective	Less Effective
Flash rate	Faster (> 1 Hz)	Slower ($\leq$ 1 Hz)
Color	Red, White	Blue
Beam focus	Hemispherical	Narrow beam
Flash device type	LED	Incandescent, Flashtube
Effective intensity	More Intense (> 10 cd)	Less Intense (< 5 cd)
Flash pattern	S-O-S/irregular	Regular

6.1.2 Ergonomics

Even after down-selecting among several types of VDSD technologies and narrowing the field within the types selected, the devices tested in this study came in a wide variety of approaches, features, and configurations. Many of the characteristics seen in a device can become a positive trait under one scenario and a negative trait in another. One example is a focused beam, which can produce an intense signal in a very small device when aimed properly, but can be ineffective if the scenario assumes that the user has no knowledge of where to aim. Another example is a signal that is very intense over 360° but is very difficult to use due to its weight under a scenario that requires that it be held in the air by hand. A third example is using replaceable batteries to have a more predictable device expiration date, vs. having common replaceable batteries, understanding that batteries may be removed, and that batteries with less capacity may be inserted.

The insights gained by this portion of the testing can best be summarized by the device characteristics provided above in Table 15, combined with the understanding that any one or two of the stated characteristics could be the subject of a separate study to determine the best design. In addition, the need to fully develop the scenario and assumptions for use is essential to pursuing further study to identify the most important ergonomic characteristics and the best design for achieving those characteristics. It is probable that industry could design a VDSD to maximize desired characteristics, but the critical evolution is defining the tradeoffs that will need to be made to best meet the operational and design requirements.

Several VDSD characteristics that made a device more usable and ergonomic, based on the defined scenario, were identified by this study, and are summarized above in Table 15.

6.2 Recommendations

1. Recommend that effective intensity, as measured in the lab, be used in place of field studies to estimate visual detection range for VDSDs in specified meteorological conditions.
2. Recommend further study to examine the effective intensity differences between different colored devices, to determine which colors are more effective at attracting attention. Different colored devices should be compared after they have been determined to have the same intensities (accounting for differences in visual response at different wavelengths) and flash patterns to isolate the contribution of color on the subjective effectiveness of VDSDs.
3. Recommend further study in the area of flash rates. Although quicker flash rates were preferred in this study, that conclusion is based on a few observer comments. Also, many factors should be considered to better understand how faster flash rates would compare with existing non-distress signals.
4. Recommend further study to investigate flash patterns and irregular flash characteristics to identify desirable traits for VDSDs, as this aspect was very limited in the present study.
5. Recommend the most likely scenario or scenarios for a vessel distress be refined, with an eye towards prioritizing the operational and design tradeoffs that may be required for an optimum VDSD, ideally identifying traits that perform well in most or all scenarios.
6. Recommend that, after developing the most likely scenario or scenarios as noted above, further studies focus on a manageable set of ergonomic requirements to determine the most desirable characteristics and the best implementations of those characteristics. In studying this area further, consider the overall tradeoff between one best device and several classes of devices that within a class would have standard methods of operation.

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APPENDIX A CRITICAL OPERATIONAL ISSUES

COIs Used for Individual Device Testing and Head-to-Head Comparison Testing

1. How easily can shore-side observers visually acquire the signal with the unaided eye at night?
   1.1. **Criteria.** Detectable at 5 NM, 2.5 NM, and 1 NM distances from the observers' location. Apparent brightness of the device will be rated on scale of 0 to 4 by observer. A rating of 0 indicates that the signal was not visible.
   1.2. **Rationale.** The device must be visually apparent to function as a location device during a rescue operation. This criterion will be evaluated by determining the subjective brightness of the signals being tested.
2. Is the signal clearly distinguishable among background lighting?
   2.1. **Criteria**: Distinguishable at 5 NM, 2.5 NM, and 1 NM distances from the observers location. Rated on scale of 0 to 4 by observer. A rating of 0 indicates that the signal was not visible.
   2.2. **Rationale**: Background lighting will frequently be present during search and rescue operations, and easily distinguishing between distress signaling device and other environmental light sources will improve the effectiveness of a given device.
3. Is the device clearly distinguishable from other light sources typical in or near the maritime environment?
   3.1. **Criteria**: Distinguishable at 5 NM, 2.5 NM, and 1 NM distances from the observers location. Rated on scale of 0 to 4 by observer. A rating of 0 indicates that the signal was not visible.
   3.2. **Rationale**: Lights in and around the maritime environment are used for multiple purposes; therefore, the ability of a device to clearly indicate distress (e.g., as opposed to a navigation light) will improve its effectiveness as a distress signal.
4. Is the signal omni-directional?
   4.1. **Criteria**: Different device orientations will be tested using the criteria in steps 1 through 3. The comparison of the test results will be evaluated to determine the directionality of the device.
   4.2. **Rationale**: Many of the candidate signals have narrow effective illumination cone angles, potentially limiting their effectiveness in signaling rescuers who are not apparent to the individual signaling distress. Similarly, the effectiveness may be limited if an individual is not capable of physically directing the signal towards rescuers. Conversely, an omni-directional signal may not have the effective range of a focused signal. By evaluating multiple signaling orientations, the qualities of focused vs. omni-directional devices will be investigated.

COIs used for Ergonomic Testing

5. Is the device easy to energize even with limited lighting?
   5.1. **Criteria**: The device must be designed to be easily operable in limited lighting. Instructions printed on the device, if any, must be easy to understand. Subjective ease of energizing the device will be rated on a scale of 1 to 5 by the user.
   5.2. **Rationale**: The device may need to quickly be energized in a distress situation with limited lighting, and with limited time to read or decipher instructions.
   5.3. **User survey questions used:**
      5.3.1. The device was easy to activate
      5.3.2. I could have activated the device without reading the instructions; operation was obvious
      5.3.3. The "on" switch was located in an obvious location
      5.3.4. The device instructions were clear and concise
      5.3.5. There was enough light to easily read the instruction
      5.3.6. I activated the device quickly

6. Once initiated, is the device easy to use?
   6.1. **Criteria**: The device must be designed to be used easily in the correct manner. Operation must be self-explanatory, or easily understandable instructions must be printed on the device. Correct use must not require constant interaction or difficult adjustments to the device. Ease of use will be rated on scale of 1 to 5 by user.
   6.2. **Rationale**: Once initiated, a distress signal must be correctly held or orientated, under difficult circumstances, with limited lighting and with limited time to read or decipher instructions, to make best use of the intended signal and maximize the probability of attracting the attention of rescuers.
   6.3. **User survey questions used:**
      6.3.1. Optimum position to deploy device?
      6.3.2. Overall ease of use?
7. Is the signal's weight and configuration suitable for the user?
   7.1. **Criteria**: The device must be lightweight enough and have a logical grip to allow the user to hold it in the proper operational position for sustained periods with one hand. The weight of the device will be recorded. The subjective ease in which it is held up in one hand will be rated on scale of 1 to 5 by the user.
   7.2. **Rationale**: If on a boat, holding the device up increases its visibility over waves and the visible horizon. If in the water, the device must be held up out of the water to most effectively be seen. In many distress situations, the person in distress will need to use his/her other hand to hold onto the boat, debris, or another person.
   7.3. **User survey questions used:**
      7.3.1. The device is very easy to hold in the deployed position.
      7.3.2. I could hold the device in this deployed position for hours very comfortably.
8. Can the signal be used with limited dexterity?
   8.1. **Criteria**: The device should be capable of being energized, employed, and held aloft with gloved hands (ideally with one gloved hand). The ease of performing these functions will be rated on scale of 1 to 5 by the user.
   8.2. **Rationale**: The dexterity of a user may be limited due to injury, wearing gloves, or due to cold. Testing the use of these devices with gloved hands will simulate each of these limited manual dexterity scenarios.
   8.3. **User survey questions used:**
      8.3.1. The device is easy to turn on with a glove on my hands
      8.3.2. The device is easy to turn on with one hand
9. Is the device durable and survivable (drop, float, immerse)? The below criteria will be applied in the sequence shown.
   9.1. **Criteria**:
      9.1.1. Device must be functional after a single 8-ft drop to a concrete surface. Following the drop, the device must (1) function and (2) have no visible damage (cracks, broken lens, etc.) based on an examination by an SME. A rating of 0, 1, 2, or 3 will be applied by an SME, depending on a finding of: no damage, does not function, visible damage, or a combination of does not function/visible damage, respectively. Damage, if any, will be characterized.
      9.1.2. Device must float in freshwater. A rating of 0, 1 will be applied by an SME.
      9.1.3. Device must survive immersion under water (non-manipulated immersion). The device will be immersed 1 ft underwater without manipulating any device controls. A rating of 0, 1 will be applied by an SME, depending on whether it operates after retrieval from the water and a 30-second wait time, and whether there are no visible signs of water intrusion by external observation.
   9.2. **Rationale**: Devices may be dropped on the deck, or in the water in normal use.

9.3. **SME tested by performing drop test, float test, and immersion test**.

10. Does the device require special storage requirements, such as environmental control?
    10.1. **Criteria**: Must be designed for typical storage on a recreational boat. This criterion will be rated by an SME as SAT (satisfactory) (no storage requirements) or UNSAT (unsatisfactory) (storage requirements) in order for a device to meet a 2+ year storage lifetime (expiration date) from the manufacture date. A requirement that a device be stored out of the weather will not be considered a "special" storage requirement.
    10.2. **Rationale**: Storage compartments on recreational boats typically do not provide for any type of environmentally controlled storage.
    10.3. **SME tested using the following characteristics**:
        10.3.1. Device dimensions and SAT, UNSAT storage requirements
11. Is the device susceptible to inadvertent activation during storage?
    11.1. **Criteria**: The device must require positive action for activation. This criterion will be rated on a scale of 1 to 5 by an SME.
    11.2. **Rationale**: If the device is unintentionally activated during storage, the battery will be discharged and the device will not be operational in an emergency situation.
    11.3. **SME tested.**
12. Is the device readily identified as a distress device?
    12.1. **Criteria:** The device must be labeled or colored in a manner such that it is easily recognizable by user as a distress device, and not common flashlight. This criterion will be rated on a scale of 1 to 5 by an SME.
    12.2. **Rationale:** In an emergency, a user needs to quickly identify emergency gear, including distress signal devices.
    12.3. **User survey questions used:**
    12.4. The device is easily identified as a distress device
13. Does the device function as expected?
    13.1. **Criteria:** The device must have an illuminant technology that quickly responds to activation and does not require a warm-up period or delay that could lead a user to believe it is not functioning. This criterion will be measured by the time duration until a visual indication (flash).
    13.2. **Rationale**: The criterion is selected to ensure the user knows the device is working correctly in a situation of distress.
    13.3. **User survey questions used**:
        13.3.1. The device activated immediately so I knew it was working right away.
        13.3.2. The device functioned properly and quickly
14. Does the device follow established ergonomic standards?
    14.1. **Criteria:** The device must have tactile grips, grip diameter between 1.25″-1.75″, and characters of at least 0.4 cm in height. The device will be rated on a scale of 1 to 5 by an SME.
    14.2. **Rationale:** This criterion is selected to adhere to the established research standards for ergonomic testing of hand-held devices as a measure of how easily the device can be manipulated.
    14.3. **SME tested.**

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APPENDIX B GOVERNMENT-FURNISHED INFORMATION (GFI) REVIEWED

1. U.S. Coast Guard Alternatives to Pyrotechnic Visual Distress Signal Devices Request for Proposal HSCG32-11-R00007.
2. Vendor responses (14) to U.S. Coast Guard Request for Proposal HSCG32-11-R00007.
3. 33 CFR 175 Subpart C: Visual Distress Signals.
4. 33 CFR Chapter I, Subchapter D: International Navigation Rules.
5. 33 CFR Chapter I, Subchapter E: Inland Navigation Rules.
6. 33 CFR 83.37 and 87.1(p): Inland Navigation Rules, Rule 37 (Distress Signals).
7. 46 CFR 160.021: Hand Held Red Flare Distress Signals.
8. 46 CFR 160.022: Floating Orange Smoke Distress Signals (5 Minutes).
9. 46 CFR 160.024: Pistol-Projected Parachute Red Flare Distress Signals.
10. 46 CFR 160.028: Signal Pistols for Red Flare Distress Signals.
11. 46 CFR 160.036: Hand-Held Rocket Propelled Parachute Red Flare.
12. 46 CFR 160.037: Hand Orange Smoke Distress Signals (50 seconds).
13. 46 CFR 160.057: Floating Orange Smoke Distress Signals (15 Minutes).
14. 46 CFR 160.066: Red Aerial Pyrotechnic Flare – 10,000 candela.
15. 46 CFR 160.072: Distress Signal for Boats, Orange Flags.
16. 46 CFR 160.121: SOLAS Hand-Held Red Distress Signal.
17. 46 CFR 160.136: SOLAS Hand-Held Red Parachute Flare.
18. 46 CFR 160.157: SOLAS Floating Orange Smoke Distress Signal.
19. 46 CFR 161.013: Electric Distress Light for Boats.
20. 46 CFR 28.145: Distress Signals for Commercial Fishing Industry Vessels.
21. COMDTINST M16130.2E, U.S. Coast Guard Addendum to the United States National Search and Rescue Supplement To The International Aeronautical and Maritime Search and Rescue Manual.
22. IALA E-200-2, Marine Signal Lights Part 2 - Calculation, Definition and Notation of Luminous Range, Edition 1, December 2008.
23. IALA E-200-3, Marine Signal Lights Part 3 - Measurement, Edition 1, December 2008.
24. IALA E-200-4, Marine Signal Lights Part 4 - Determination and Calculation of Effective Intensity Edition 1, December 2008.
25. International Regulations for Preventing Collisions at Sea (COLREGS)
26. Multi-Flick Strobe Minor Aid Light, CWO2 B. Roberts and P. Higley.
27. Naval Submarine Medical Research Laboratory Report 1202, Conspicuity of Aids to Navigation: Spatial Configurations for Flashing Lights, S. Wagner and K. Laxar, 09 August 1996.
28. U.S. Coast Guard Preliminary Visual Ranking Exercise.
29. U.S. Coast Guard Research & Development Center, Report Number CG-D-15-85, A Static Evaluation of Selected Visual Distress Signaling Devices, January 1985, R.Q. Robe and G.L. Hover.
30. U.S. Coast Guard Research & Development Center, Report Number CG-D-15-94, Conspicuity of Aids to Navigation: Temporal Patterns for Flashing Lights, March 1993, K. Laxar and S. Benoit.
31. U.S. Coast Guard Research & Development Center, SAR Distress Notification Methods and Alternatives (RDC Project 1101) - Visual Distress Signal Devices Functional Requirements Workshop. 29-30 March 2011.
32. U.S. Coast Guard Research and Development Center, Report Number CG-D-30-86, Visual Sweep Width Determination for Three Visual Distress Signaling Devices, September 1986, R.Q. Robe and G.L. Hover.

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APPENDIX C PARTICIPANT BACKGROUND INFORMATION

Participant Background Information

Please provide information regarding your previous experience with signal flares by circling/filling in answers to the following questions. All answers will remain confidential and will be correlated with survey results only through a participant number.

1. Have you witnessed a visual distress signal used in an emergency situation? Yes No

   If yes, answer following questions. (If you have witnessed more than one event, please provide details about additional sightings on the back of this page.)

   a. How many events (approximately) have you witnessed? 1 2-4 5-10 >10
   b. Did you immediately recognize the signal as indicating distress? Yes No
   c. At the time, were you looking for a vessel in distress? Yes No
   d. Please describe the following information about the incident:

      What were the on-scene weather conditions? ____

      What was your distance from the signal? ____

      When you witnessed the signal, were you Ashore On a vessel

2. Have you ever interviewed or questioned anyone about their sighting (or perceived sighting) of a distress signal? Yes No

   If yes, answer following questions.

   a. Was the witness able to clearly describe what he or she saw? Yes No
   b. Was the witness certain that the signal he or she saw was a distress signal? Yes No
   c. Was the sighting confirmed independently of the observer? Yes No

3. Have you seen a signal flare used in a non-emergency situation (e.g., testing or training)?Yes No

4. Do you normally wear glasses or contact lenses? Yes No

   If yes, please circle the best description of why:

   near-sighted far-sighted astigmatism

   Will you be wearing glasses or contact lenses during the test? Yes No

Please indicate any additional information about your vision, especially any color vision problems, that may impact your detection of rescue signals:

____

____

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APPENDIX D BOAT PROCEDURES FOR INDIVIDUAL DEVICE TESTING

D.1 General Test Preparation

Each device was labeled with a Device Designation (black printing on a white tag), and these numbers were in the test script to indicate the device tested. Prior to testing the devices, the TC familiarized himself with the operation of each device; specifically, how to switch each device on and off, and how to select the appropriate operation mode (if applicable). After this familiarization, the TC placed new batteries in the devices and checked to confirm they were working properly. No issues were noted in the performance of the devices.

D.2 Individual Device Operation

The TC on the boat energized each device when directed by the TD, repeating the direction received to confirm it was received correctly. The TC activated the devices under cover prior to starting the test, to prevent "flashing" the observers and allowing any extraneous light to give a false start to the test. When the device was energized and held in the proper position, the TC uncovered the light for the duration of the test, and then immediately covered it when directed by the TD to end the test.

The TC operated each device from the same seated position in the rear of the boat, and used a lanyard between the neck and wrist to lock the arm position in the same place each time. Using these procedures, the TC easily maintained and repeated the 90° and 45° positions for each test. The TC calculated his hand position at 5 ft above the water's surface, factoring in the deck height above the water. During each test, the TC positioned each device (when not in a vertical orientation) towards the observers, by aiming each device towards Point Judith Light and positioning the boat to ensure that the device signal would be unobstructed. The Coast Guard Auxiliary crew did an outstanding job of keeping the boat on station for each test and keeping the stern of the boat facing the light.

- Device Orientation. The devices were subdivided into two categories according to their form factors (clip-on style devices 2, 6, 9, 10, and 11) and flashlight style devices (1, 3, 4, 5, 7, and 8). Because the intensity of these devices can vary drastically depending on the observation angle, the orientation of the devices was specified for each test.
- Clip-On Style Devices. For the clip-on devices, 90° on-axis and 45° off-axis orientations were tested (see Figure D-1). The 45° off-axis orientation was chosen based on the performance of the device. During on-axis testing, the brightest illumination area of the device was pointed directly at the observers' location. For the 45° orientation, the device was pointed at a 45° angle directly above the observers.
- "Flashlight" Style Devices. For the flashlight style devices, vertical and 45° axis orientations were tested (see Figure D-2). During vertical testing, the device was held with its body oriented vertically such that the globe of the device was pointing directly in the air. For the 45° orientation, the device was pointed at a 45° angle directly above the observers.

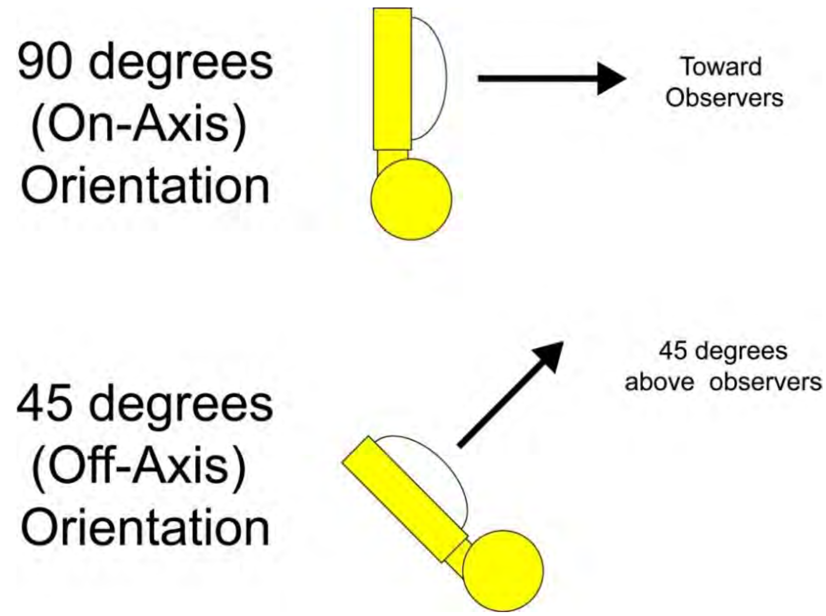

Figure D-1. Testing orientation of "clip-on" style devices.

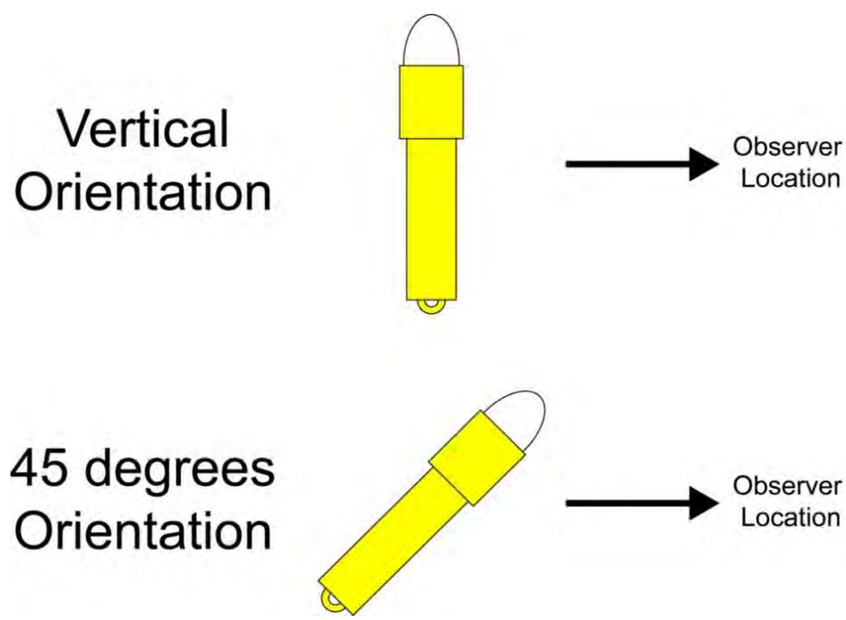

Figure D-2. Testing orientation.

APPENDIX E POST TESTING QUESTIONNAIRE

Post Testing Questionnaire

1. Did one particular signal seem ***more effective*** than the others? If so, please describe what made it effective. If you remember, please also indicate test number of the signal.

2. Did one signal seem ***less effective*** than the others? If so, please describe what made it effective. If you remember, please also indicate test number of the signal.

3. Considering all of the items tested, were there any general characteristics of the signals that made some ***more effective*** than others? If so, please describe what made it effective. If you remember, please also indicate test number of the signal.

4. Considering all of the items tested, were there any general characteristics of the signals that made some ***less effective*** than others? If so, please describe what made it effective. If you remember, please also indicate test number of the signal.

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APPENDIX F WEATHER OBSERVATIONS FOR INDIVIDUAL DEVICE TESTING

Table F-1. Individual device: air observations 18 October 2011 Newport State Airport (KUUU).

Time (EDT)	Temp. (°F)	Dew Point (°F)	Humidity (%)	Pressure (in.)	Visibility (mi.)	Conditions
1553	64.0	39.0	40	29.87	10.0	Mostly Cloudy
1653	63.0	41.0	45	39.88	10.0	Scattered Clouds
1753	61.0	43.0	52	29.89	10.0	Clear
1853	57.0	46.0	67	29.91	10.0	Clear
1953	54.0	48.0	80	29.91	10.0	Clear
2053	55.9	52.0	87	29.92	10.0	Mostly Cloudy
2153	55.9	53.1	90	29.94	10.0	Overcast
2253	57.0	54.0	89	29.94	10.0	Cloudy
2353	54.0	53.1	97	29.94	10.0	Partly Cloudy

*Eastern daylight time

Table F-2. Individual device: astronomical information.

Date	Sunset	Nautical Twilight	Astronomical Twilight	Moon Rise	Moon	
Tuesday, October 18, 2011	1800	1900	1932	2235	65%	

Source of data: Weather Underground Location: Newport State Airport (KUUU)

Table F-3. Individual device: tidal data.

`					Newport				
Date	Day	Time	Height	High/Low	Date	Day	Time	Height	High/Low
10/18/2011	Tue	0012	2.53	H	10/18/2011	Tue	0012	2.96	H
10/18/2011	Tue	1845	0.77	L	10/18/2011	Tue	1807	0.83	L

Source of data: http://www.noaa.gov/

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APPENDIX G RANKED RESULTS FOR INDIVIDUAL DEVICE TESTING

Table G-1. Ranked results for individual device testing.

< Rank on 1st series					5 NM	Observer # >	14	5	10	8	4	13	1	9	2	12	6	7	11	3	Average			Total
	Test #	Color	Type	Device	Mode	Orientation	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1	2	3	1+2+3
1	5-09	White	LED	19	N/A	45°	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	3 3 4	1 2 1	3.7	3.8	3.8	11.3
2	5-18	Red	LED	20	Flashing Red	Vertical	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 3 3	4 4 4	3 3 3	4 4 4	4 4 4	4 4 3	3 3 3	4 3 3	2 2 0	3.7	3.6	3.4	10.6
3	5-19	Red/White	LED	20	Flashing Red/White	Vertical	4 4 4	4 3 4	4 4 4	4 4 4	3 2 3	4 4 4	4 4 4	3 3 3	3 3 3	4 4 4	4 3 3	3 3 3	2 2 2	1 1 0	3.4	3.1	3.2	9.7
4	5-12	Red	LED	17	S-O-S	90° (on axis)	4 4 4	3 4 3	4 3 4	3 4 4	4 4 4	3 2 3	4 2 2	3 3 3	3 4 4	4 4 4	3 2 1	2 2 2	3 2 2	2 2 1	3.2	3.0	2.9	9.1
5	5-17	White	LED	20	Flashing White	Vertical	4 4 2	3 3 2	3 3 4	3 3 4	3 3 3	4 4 4	4 3 3	3 3 3	3 4 4	2 2 2	4 3 4	3 2 3	1 2 3	1 1 0	2.9	2.9	2.9	8.7
6	5-10	Red	LED	17	Flashing	90° (on axis)	4 4 4	1 1 2	4 4 4	4 4 4	4 4 4	3 1 2	3 3 3	2 1 1	3 4 4	3 4 4	3 3 4	2 3 2	1 1 2	0 0 0	2.6	2.6	2.9	8.1
7	5-06	White	LED	18	Flashing	90° (on axis)	3 4 4	2 3 3	3 2 3	3 3 2	2 3 2	3 3 4	3 3 3	3 2 3	3 3 3	3 2 3	3 3 3	2 1 1	2 2 3	1 1 1	2.6	2.5	2.7	7.8
8	5-08	White	LED	18	S-O-S	90° (on axis)	4 4 4	1 2 1	2 2 2	2 1 3	3 3 4	3 4 4	3 1 2	1 1 2	2 3 3	0 0 0	2 1 3	3 1 3	1 1 1	1 1 1	2.0	1.8	2.4	6.1
9	5-15	Green	LED	16	Flashing	90° (on axis)	2 3 2	1 2 2	1 1 1	2 3 3	3 2 2	2 3 3	2 3 4	3 2 1	1 2 1	1 1 1	1 1 1	2 1 2	1 1 1	1 1 0	1.6	1.9	1.7	5.2
10	5-13	Blue	LED	15	Flashing	90° (on axis)	2 3 3	2 1 1	1 1 1	3 2 3	1 3 3	1 2 3	2 2 0	3 3 2	1 2 2	1 1 1	1 1 1	2 1 1	1 1 2	1 1 0	1.6	1.7	1.6	4.9
11	5-04	White	LED	13	N/A	45°	2 3 3		1 1 1	1 1 1	1 2 2	1 1 1	0 0 0	1 1 1	1 2 2	0 0 0	0 0 0	1 1 1	0 0 0	1 1 1	0.8	1.0	1.0	2.8
12	5-03	White	F.L.	12	N/A	45°	2 1 1		0 0 0	1 1 1	2 2 2	0 0 0	1 0 0	1 1 1	1 2 3	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0	0.7	0.6	0.7	2.0
13	5-14	Blue	LED	15	Flashing	45°	1 1 1	0 0 0	0 0 0	0 0 0	1 1 1	0 0 0	1 1 1	0 0 0	1 0 0	1 1 1	0 0 0	0 0 0	1 1 1	0 0 0	0.4	0.4	0.4	1.1
14	5-01	White	F.L.	3	N/A	45°	2 1 2		1 1 1	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.4	0.3	0.4	1.1
15	5-11	Red	LED	17	Flashing	45°	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	3 2 3	1 0 0	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0.4	0.3	0.4	1.1
16	5-02	White	Incand.	4	N/A	90° (on axis)	2 2 2		0 0 0	0 0 0	0 0 0	0 0 0	1 2 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.2	0.3	0.2	0.8
17	5-05	White	F.L.	14	N/A	45°	0 0 0	1 1 1	0 0 0	1 1 1	1 2 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.2	0.3	0.2	0.7
18	5-16	Green	LED	16	Flashing	45°	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 1 1	0 0 0	0.1	0.1	0.1	0.4
19	5-07	White	LED	18	Flashing	45°	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	0.1	0.1	0.1	0.2

					2.5 NM	Observer # >	14	5	10	8	4	13	1	9	2	12	6	7	11	3	Average			Total
	Test #	Color		Device	Mode	Orientation	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1	2	3	1+2+3
1	2-06	White	LED	19	N/A	45°	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 3	3 3 3	3.9	3.9	3.9	11.7
8	2-07	White	LED	18	S-O-S	90° (on axis)	4 4 4	4 4 4	4 4 4	4 3 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 3 4	4 3 4	4 4 4	3 3 3	3.9	3.7	3.9	11.6
6	2-05	Red	LED	17	Flashing	90° (on axis)	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	3 4 3	4 4 3	4 4 4	4 4 4	2 3 3	4 4 4	3 3 3	3.7	3.9	3.7	11.3
4	2-03	Red	LED	17	S-O-S	90° (on axis)	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 4	4 4 3	4 4 1	4 4 4	4 2 3	4 3 3	4 3 4	3 3 2	3.9	3.6	3.4	11.0
9	2-16	Green	LED	16	Flashing	90° (on axis)	4 4 4	4 4 4	4 4 4	3 4 4	3 3 3	4 4 4	4 4 4	4 4 4	4 4 4	3 4 4	4 3 4	3 4 3	3 4 4	2 2 2	3.5	3.7	3.7	10.9
2	2-18	Red	LED	20	Flashing Red	Vertical	4 4 4	4 4 4	4 3 4	4 3 4	4 4 4	4 4 4	4 4 4	4 4 4	4 3 1	4 4 4	4 4 4	4 3 4	4 3 2	2 2 2	3.9	3.5	3.5	10.9
7	2-09	White	LED	18	Flashing	90° (on axis)	4 4 4	4 4 4	3 4 4	3 4 4	4 3 3	3 4 4	4 4 4	2 4 3	4 4 4	3 4 4	3 4 4	4 2 4	3 4 4	3 2 3	3.4	3.6	3.8	10.8
3	2-19	Red/White	LED	20	Flashing Red/White	Vertical	4 4 4	4 4 4	4 3 4	4 4 4	4 3 2	4 4 4	4 4 4	4 4 4	4 3 1	3 4 4	4 4 4	3 1 2	3 3 3	2 3 2	3.6	3.4	3.3	10.4
5	2-17	White	LED	20	Flashing White	Vertical	4 4 4	3 2 3	3 3 3	3 3 4	3 2 2	4 4 4	4 4 4	4 4 3	3 2 1	3 4 4	4 2 3	4 3 4	3 3 3	1 2 1	3.3	3.0	3.1	9.4
11	2-11	White	LED	13	N/A	45°	3 3 2	3 4 3	2 2 2	2 3 3	2 2 2	3 2 3	3 2 3	3 2 2	4 3 2	3 3 3	2 2 3	3 3 2	2 2 3	1 1 0	2.6	2.4	2.4	7.4
10	2-02	Blue	LED	15	Flashing	90° (on axis)	4 4 4	4 4 4	1 1 1	2 1 2	1 1 2	4 4 4	0 0 0	2 2 1	2 1 2	1 1 1	1 1 1	1 1 0	0 0 0	1 1 1	1.7	1.6	1.6	4.9
12	2-12	White	F.L.	12	N/A	45°	2 3 2	3 2 2	1 1 1	1 1 2	1 3 2	2 1 3	1 0 1	1 2 1	2 1 1	1 1 1	1 1 1	1 1 1	1 1 1	1 1 0	1.4	1.4	1.4	4.1
16	2-13	White	Incand.	4	N/A	90° (on axis)	2 3 2	2 1 1	1 1 2	1 1 1	1 1 1	1 1 1	1 0 1	1 2 1	2 1 1	1 1 1	1 1 1	2 1 1	1 1 1	1 1 0	1.3	1.1	1.1	3.5
15	2-04	Red	LED	17	Flashing	45°	2 2 3	1 1 1	1 1 1	1 1 1	0 0 0	0 0 0	1 0 0	2 1 1	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0.6	0.4	0.5	1.6
18	2-15	Green	LED	16	Flashing	45°	1 2 1	1 1 1	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	1 1 1	1 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0.4	0.4	0.3	1.1
17	2-10	White	F.L.	14	N/A	45°	1 1 1	0 0 0	0 0 0	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0	0.2	0.1	0.1	0.5
13	2-01	Blue	LED	15	Flashing	45°	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.1	0.1	0.1	0.2
19	2-08	White	LED	18	Flashing	45°	1 1 1	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.1	0.1	0.1	0.2
14	2-14	White	F.L.	3	N/A	45°	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.0	0.0	0.0	0.0

Table G-1. Ranked results for individual device testing (Continued).

< Rank on 1st series					1 NM	Observer # >	14			5			10			8			4			13			1			9			2			12			6			7			11			3			Average			Total
	Test #	Color		Device	Mode	Orientation	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1+2+3
1	1-09	White	LED	19	N/A	45°	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4.0	3.9	3.9	11.9
9	1-15	Green	LED	16	Flashing	90° (on axis)	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3.9	4.0	3.9	11.9
7	1-06	White	LED	18	Flashing	90° (on axis)	4	4	3	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	2	3.9	3.9	3.8	11.5
6	1-10	Red	LED	17	Flashing	90° (on axis)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	2	3	3	4	4	4	3	4	3	3.8	3.9	3.7	11.4
3	1-19	Red/White	LED	20	Flashing Red/White	Vertical	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	1	4	4	4	4	2	4	4	3	4	4	4	3	4	4	3	4.0	3.6	3.6	11.3
11	1-04	White	LED	13	N/A	45°	4	4	3	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	3	3	4	4	4	4	2	2	4	4	4	4	3	4	4	4	4	4	3	3	4	3	3	4.0	3.6	3.5	11.1
5	1-17	White	LED	20	Flashing White	Vertical	4	4	4	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	1	4	4	4	4	3	4	4	3	4	4	4	2	4	4	4	3.9	3.6	3.6	11.0
2	1-18	Red	LED	20	Flashing Red	Vertical	4	4	4	4	4	4	4	3	4	4	3	3	4	4	4	4	4	3	4	4	4	4	4	4	4	3	1	4	4	4	4	2	4	4	4	4	4	4	2	3	3	3	3.9	3.6	3.4	10.9
4	1-12	Red	LED	17	S-O-S	90° (on axis)	3	3	3	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	2	2	4	4	4	4	4	2	4	4	4	4	3	3	3	2	3	4	4	4	4	4	4	3.8	3.5	3.5	10.8
8	1-08	White	LED	18	S-O-S	90° (on axis)	4	4	3	4	3	4	4	4	4	4	3	4	4	3	3	4	4	4	4	3	4	2	2	1	4	4	4	3	4	4	4	2	3	3	3	3	4	3	4	3	3	3	3.6	3.2	3.4	10.3
10	1-13	Blue	LED	15	Flashing	90° (on axis)	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	3	2	3	3	3	2	3	3	2	2	2	3	4	2	3	2	3.4	3.4	3.5	10.3
12	1-03	White	F.L.	12	N/A	45°	4	4	3	4	4	4	4	4	4	3	3	3	4	4	3	4	4	4	4	2	2	3	4	3	4	3	1	2	3	3	4	3	3	4	4	4	4	3	3	3	3	3	3.6	3.4	3.1	10.1
16	1-02	White	Incand.	4	N/A	90° (on axis)	4	4	3	4	2	4	2	2	3	3	2	3	4	4	3	4	3	4	2	1	2	3	3	3	4	3	2	2	3	3	4	3	3	4	4	4	4	3	3	2	2	1	3.3	2.8	2.9	9.0
17	1-05	White	F.L.	14	N/A	45°	2	3	2	3	4	4	2	3	3	2	3	3	2	3	3	2	2	2	1	1	1	3	3	3	3	1	1	1	2	1	3	2	3	2	1	2	2	2	2	1	2	1	2.1	2.3	2.2	6.6
15	1-11	Red	LED	17	Flashing	45°	3	3	2	3	3	4	2	3	3	2	2	3	2	2	3	0	0	0	1	1	1	2	1	1	3	2	1	1	2	1	2	2	3	1	2	1	2	2	3	0	0	0	1.7	1.8	1.9	5.4
19	1-07	White	LED	18	Flashing	45°	2	3	2	3	3	3	1	2	2	2	2	3	1	2	2	1	1	1	1	1	1	1	1	1	4	2	1	1	1	1	2	1	1	1	2	1	1	1	1	1	1	1	1.6	1.6	1.5	4.7
18	1-16	Green	LED	16	Flashing	45°	2	3	1	2	2	2	1	1	1	1	2	3	2	2	2	2	1	1	1	0	0	2	2	1	4	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1.6	1.4	1.2	4.3
14	1-01	White	F.L.	3	N/A	45°	3	3	2	2	3	2	1	1	1	2	1	2	1	1	2	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1.4	1.2	1.2	3.8
13	1-14	Blue	LED	15	Flashing	45°	1	2	1	2	2	2	1	1	1	1	1	2	2	1	1	2	1	2	1	0	0	1	2	1	3	1	1	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1.2	1.0	1.0	3.2

					1 NM-B	Observer # >	14			5			10			8			4			13			1			9			2			12			6			7			11			3			Average			Total
	Test #	Color		Device	Mode	Orientation	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1+2+3
1	1B-09	White	LED	19	N/A	45°	4	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3.9	3.9	3.7	11.6
4	1B-12	Red	LED	17	S-O-S	90° (on axis)	4	4	4	4	4	3	4	4	4	4	3	3	4	4	4	4	4	3	4	4	4	4	4	3	4	3	1	4	4	4	4	2	4	4	4	4	4	3	4	4	4	4	4.0	3.6	3.5	11.1
9	1B-15	Green	LED	16	Flashing	90° (on axis)	4	4	4	4	4	4	4	4	4	3	4	3	2	3	2	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	3	4	3	3	3	3	4	4	4	3.6	3.9	3.6	11.1
6	1B-10	Red	LED	17	Flashing	90° (on axis)	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	3	1	4	4	4	4	4	4	3	4	4	4	4	4	2	1	3	3.7	3.6	3.6	11.0
8	1B-08	White	LED	18	S-O-S	90° (on axis)	4	3	3	4	4	4	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4	4	4	4	4	2	1	4	4	4	4	3	4	4	3	3	4	3	4	2	2	2	3.8	3.4	3.4	10.6
7	1B-06	White	LED	18	Flashing	90° (on axis)	4	4	3	4	4	4	4	4	4	3	4	4	3	3	3	4	4	4	4	3	4	4	4	3	4	3	2	4	4	4	4	4	4	2	3	2	3	3	4	2	2	1	3.5	3.5	3.3	10.3
5	1B-17	White	LED	20	Flashing White	Vertical	3	3	2	4	4	4	4	4	4	3	4	4	4	4	3	4	4	4	3	2	2	4	4	4	4	2	1	4	4	4	4	2	4	4	4	3	4	3	2	3	3	3	3.7	3.4	3.1	10.2
2	1B-18	Red	LED	20	Flashing Red	Vertical	3	3	2	4	4	3	4	3	4	4	3	3	4	4	4	4	4	4	4	4	3	4	4	4	4	2	1	4	4	4	4	2	3	2	2	1	4	3	2	4	4	4	3.8	3.3	3.0	10.1
3	1B-19	Red/White	LED	20	Flashing Red/White	Vertical	4	4	4	4	4	4	4	3	4	3	4	4	2	2	2	4	4	4	4	4	3	4	4	1	4	2	1	4	4	4	4	3	3	2	2	2	4	3	3	4	4	4	3.6	3.4	3.1	10.1
11	1B-04	White	LED	13	N/A	45°	4	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	1	1	3	3	3	4	2	1	2	2	2	4	4	4	2	2	2	3	3	2	2	1	1	3.0	2.4	2.4	7.8
10	1B-13	Blue	LED	15	Flashing	90° (on axis)	4	4	4	4	4	4	2	4	4	1	2	1	2	3	2	3	4	4	3	2	1	3	4	4	4	4	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2.2	2.6	2.3	7.1
12	1B-03	White	F.L.	12	N/A	45°	4	3	2	3	3	3	3	2	3	2	3	2	2	2	2	3	2	3	3	2	3	2	2	1	4	1	1	1	2	2	3	2	2	1	1	1	3	2	2	1	2	1	2.5	2.1	2.0	6.6
16	1B-02	White	Incand.	4	N/A	90° (on axis)	3	3	1	3	3	2	2	2	2	3	2	3	1	1	1	1	1	1	1	1	1	1	1	1	4	2	1	1	2	2	3	3	2	2	1	1	2	2	2	1	2	1	2.0	1.9	1.5	5.4
15	1B-11	Red	LED	17	Flashing	45°	2	2	1	1	1	1	1	1	2	1	2	1	2	3	2	0	0	0	1	1	1	1	1	1	4	3	1	1	1	1	2	1	3	1	1	1	1	1	2	0	0	0	1.3	1.3	1.2	3.8
17	1B-05	White	F.L.	14	N/A	45°	2	2	1	2	2	2	1	1	1	1	2	2	0	0	0	0	0	0	2	1	1	2	1	1	3	1	1	1	1	1	1	1	1	1	2	1	0	0	0	0	0	0	1.1	1.0	0.9	3.0
19	1B-07	White	LED	18	Flashing	45°	3	3	1	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0.5	0.4	0.3	1.2
18	1B-16	Green	LED	16	Flashing	45°	2	3	1	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0.4	0.4	0.2	1.0
14	1B-01	White	F.L.	3	N/A	45°	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0
13	1B-14	Blue	LED	15	Flashing	45°	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0

Table G-1. Ranked results for individual device testing (Continued).

< Rank on 1st series			2.5 NM-B			Observer # >	14			5			10			8			4			13			1		
	Test #	Color	Device		Mode	Orientation	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
2	2B-18	Red	LED	20	Flashing Red	Vertical	4	4	3	4	3	3	3	3	4	2	3	2	3	3	3	4	4	4	4	3	2
4	2B-03	Red	LED	19	S-O-S	90° (on axis)	3	2	0	0	0	0	2	2	2	3	2	2	3	3	3	2	2	1	4	4	4
8	2B-07	White	LED	18	S-O-S	90° (on axis)	4	3	2	3	3	2	2	3	2	2	3	2	2	2	2	4	2	3	4	3	2
1	2B-06	White	LED	19	N/A	45°	3	3	2	4	4	3	2	3	3	3	3	2	3	3	3	1	1	1	4	3	2
3	2B-19	Red/White	LED	20	Flashing Red/White	Vertical	4	4	2	3	3	4	3	3	4	2	3	1	2	2	2	1	1	1	3	2	2
9	2B-16	Green	LED	16	Flashing	90° (on axis)	4	4	3	4	4	3	3	4	4	0	0	0	3	3	3	0	0	0	1	1	1
5	2B-17	White	LED	20	Flashing White	Vertical	4	4	3	3	3	2	3	3	3	1	2	1	1	1	1	0	0	0	3	2	1
6	2B-05	Red	LED	17	Flashing	90° (on axis)	3	3	3	0	0	0	1	1	2	2	3	2	0	0	0	0	0	0	4	3	4
11	2B-11	White	LED	13	N/A	45°	3	3	1	4	4	3	2	2	2	1	1	1	0	0	0	0	0	0	2	1	1
7	2B-09	White	LED	18	Flashing	90° (on axis)	1	1	1	0	0	0	1	2	1	1	2	1	0	0	0	0	0	0	1	0	0
13	2B-01	Blue	LED	15	Flashing	45°																					
10	2B-02	Blue	LED	15	Flashing	90° (on axis)																					
15	2B-04	Red	LED	17	Flashing	45°																					
19	2B-08	White	LED	18	Flashing	45°																					
17	2B-10	White	F.L.	14	N/A	45°																					
12	2B-12	White	F.L.	12	N/A	45°																					
16	2B-13	White	Incand.	4	N/A	90° (on axis)																					
14	2B-14	White	F.L.	3	N/A	45°																					
18	2B-15	Green	LED	16	Flashing	45°																					
						Observer # >	14			5			10			8			4			13			1		
					Average Observer Rating		2.802			2.646			2.407			2.368			2.275			2.267			2.213		

< Rank on 1st series		9			2			12			6			7			11			3			Average			Total
	Test #	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1+2+3
2	2B-18	1	1	1	4	2	1	4	4	4	3	2	3	1	1	2	2	2	1	2	2	1	2.9	2.6	2.4	8.0
4	2B-03	1	1	1	4	2	2	2	3	3	3	2	2	2	2	2	1	1	1	2	2	1	2.3	2.0	1.7	6.0
8	2B-07	1	1	1	3	1	1	1	1	1	2	1	1	2	2	1	1	1	1	1	1	1	2.3	1.9	1.6	5.8
1	2B-06	1	1	1	3	1	1	1	1	1	1	2	1	2	2	1	1	1	1	0	0	0	2.1	2.0	1.6	5.6
3	2B-19	1	1	1	3	1	1	0	0	0	2	1	1	1	1	1	1	1	1	1	1	1	1.9	1.7	1.6	5.2
9	2B-16	1	1	1	4	1	1	1	2	1	0	0	0	2	2	3	1	1	1	0	0	0	1.7	1.6	1.5	4.9
5	2B-17	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1.3	1.3	1.0	3.6
6	2B-05	0	0	0	4	2	1	2	1	1	1	1	3	0	0	0	0	0	0	1	1	1	1.3	1.1	1.2	3.6
11	2B-11	1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0.9	0.7	2.6
7	2B-09	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0.5	0.6	0.4	1.5
13	2B-01																									
10	2B-02																									
15	2B-04																									
19	2B-08																									
17	2B-10																									
12	2B-12																									
16	2B-13																									
14	2B-14																									
18	2B-15																									
		9			2			12			6			7			11			3			Average			Total
		2.128			2.101			2.078			2.066			1.919			1.86			1.415						

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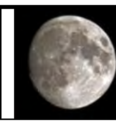
APPENDIX H WEATHER OBSERVATIONS FOR HEAD-TO-HEAD TEST

Table H-1. Head-to-head: air observations 9 November 2011 Groton/New London Airport (KGON).

Time (EDT)	Temp. (°F)	Dew Point (°F)	Humidity (%)	Pressure (in.)	Visibility (mi.)	Conditions
1556	57.0	55.0	93	30.13	10.0	Clear
1656	55.0	55.0	100	30.13	6.0	Mostly Cloudy
1756	55.9	55.9	100	30.13	8.0	Scattered Clouds
1856	55.9	55.0	97	30.12	8.0	Overcast
1956	55.9	54.0	93	30.11	9.0	Overcast
2056	57.9	55.9	93	30.10	10.0	Overcast
2156	57.0	55.9	96	30.08	10.0	Overcast
2256	57.9	55.9	93	30.06	10.0	Overcast
2356	57.9	57.0	97	30.04	10.0	Overcast

Table H-2. Head-to-head: astronomical information.

Date	Sunset	Nautical Twilight	Astronomical Twilight	Moon Rise	Moon	
Wednesday, November 18, 2011	1634	1736	1809	1544	99%	
Source of data: Weather Underground Location: Groton/New London Airport (KGON)						

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APPENDIX I ERGONOMICS TEST SURVEY

BEGIN TEST

Lighting: _______________(LUX)

TEST #____________

Subject Information:

1. Have you used a visual distress signal in an emergency situation? Yes No

If yes, please answer the following:

a. How many events (approximately) have you used a distress device? (Circle one)

1-5 6-10 > 10

b. Please describe the device you used: (Circle one)

Flare Battery Operated Signal Device Other:______________________________

2. Gender: (Circle one) Male Female

3. Circle the range that contains your current age: (Circle one)

20-29 yrs old 30-39 yrs old 40-49 yrs old >50 yrs old

4. Do you have difficulty seeing at night? (Circle one) Yes No

INSTRUCTIONS for Subject:

You will be asked to activate 14 distress signals divided into 3 groups. Start with the first device (lowest number) in the set presented to you and follow these basic steps:

1. Pick up device.
2. Activate device to a flashing strobe setting.
3. Answer questions on the design of the device.
4. Position device in a method you would use to signal a rescue searcher.
5. Select the hand position on the diagram.
6. Place gloves on hands and again attempt to activate each of devices.
7. Place device in dominant hand and attempt to activate with only that hand. You may use other surfaces of your body or items surrounding you.
8. Continue to next device.
9. After one set of devices is completed, select your favorite device from the set.
10. After all devices are tested, select overall favorite device from your three selected favorites.

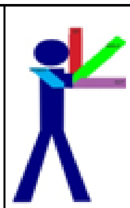
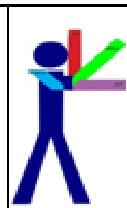
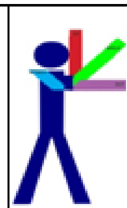
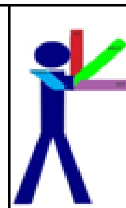
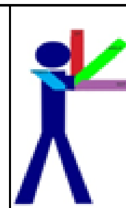
Your will be prompted throughout the test on these 10 steps. These devices are being tested in a low light situation to simulate a night time emergency on a vessel.

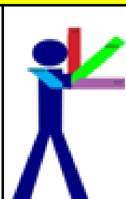
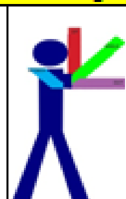
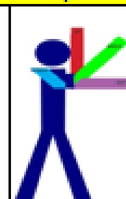
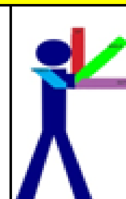
Start test:

Select a device and attempt to activate the device to its strobe mode. Once you have activated the device, answer the following questions by entering a number from 1-5 for each statement that corresponds to the scale above:

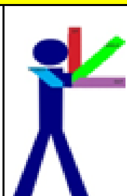
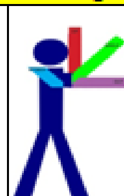
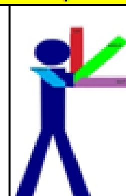
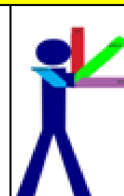
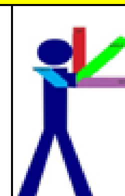
1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Set One	Device 1	Device 2	Device 3	Device 4	Device 5
ID Number					
Activate Device Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree					
The device was easy to activate					
I could have activated the device without reading the instructions; operation was obvious.					
The "on" switch was located in an obvious location					
I was able to activate the device quickly					
The device operation instructions were clear and concise					
There was enough light to easily read the instructions					
The device immediately activated so I knew it was working right away.					
The device is easily identified as a distress device					
The device functioned properly and quickly					
This device overall was easy to use.					
Demonstrate the position you would deploy the device to signal a rescue searcher Blue- attached to self Red-Vertical Green- 45 degrees Purple- Horizontal					

Please circle the arm position you would use to deploy this device or sketch a different one					
Answer questions about deployment **Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree**					
This device is very easy to hold in the deployed position					
I could hold the device in this deployed position for hours very comfortably					
Place gloves on both hands. Attempt to activate with both hands and with one					
The device is easy to turn on with a glove on my hands					
The device was easy to turn on with one hand					
Final thoughts and comments					
Please describe your overall impressions of the device. List any features you liked or disliked about the operation of the device.	1				
	2				
	3				
	4				
	5				
After set is completed, pick favorite from set					
Please select favorite device from this group of set by putting and 'X' in its box.					

Set Two	Device 6	Device 7	Device 8	Device 9	
ID Number					
Activate Device Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree					
The device was easy to activate					
I could have activated the device without reading the instructions; operation was obvious.					
The "on" switch was located in an obvious location					
I was able to activate the device quickly					
The device operation instructions were clear and concise					
There was enough light to easily read the instructions					
The device immediately activated so I knew it was working right away.					
The device is easily identified as a distress device					
The device functioned properly and quickly					
This device overall was easy to use.					
Demonstrate the position you would deploy the device to signal a rescue searcher Blue- attached to self Red-Vertical Green- 45 degrees Purple- Horizontal					
Please circle the arm position you would use to deploy this device or sketch a different one					
Answer questions about deployment Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree					
This device is very easy to hold in the deployed position					
I could hold the device in this deployed position for hours very comfortably					
Place gloves on both hands. Attempt to activate with both hands and with one					
The device is easy to turn on					

with a glove on my hands					
The device was easy to turn on with one hand					
Final thoughts and comments					
Please describe your overall impressions of the device. List any features you liked or disliked about the operation of the device.	1				
	2				
	3				
	4				
After set is completed, pick favorite from set					
Please select favorite device from this group of set by putting and 'X' in its box.					

Set Three	Device 10	Device 11	Device 12	Device 13	Device 14
ID Number					
Activate Device Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree					
The device was easy to activate					
I could have activated the device without reading the instructions; operation was obvious.					
The "on" switch was located in an obvious location					
I was able to activate the device quickly					
The device operation instructions were clear and concise					
There was enough light to easily read the instructions					
The device immediately activated so I knew it was working right away.					
The device is easily identified as a distress device					
The device functioned properly and quickly					
This device overall was easy to use.					
Demonstrate the position you would deploy the device to signal a rescue searcher **Blue- attached to self Red-Vertical Green- 45 degrees Purple- Horizontal**					
Please circle the arm position you would use to deploy this device or sketch a different one					
Answer questions about deployment Scale: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree					
This device is very easy to hold in the deployed position					
I could hold the device in this deployed position for hours very comfortably					
Place gloves on both hands. Attempt to activate with both hands and with one					
The device is easy to turn on					

with a glove on my hands					
The device was easy to turn on with one hand					
Final thoughts and comments					
Please describe your overall impressions of the device. List any features you liked or disliked about the operation of the device.	1				
	2				
	3				
	4				
	5				
After set is completed, pick favorite from set					
Please select favorite device from this group of set by putting and 'X' in its box.					

Which device number was your overall favorite? ________________

Please describe why this was your favorite device:____

____

____

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APPENDIX J USE OF GLOVES TO SIMULATE REDUCED DEXTERITY

An objective of this study was to assess the usability of the distress devices when hands were cold. Due to the difficulty of such a study, gloves were chosen to simulate the reduced dexterity that might be caused by cold. There is some research that addresses this subject. A study conducted by Glitz et al. (2009) evaluated bare hands and gloved hands in a control and a cold environment. The results of that study results are demonstrated in Figure J-1, which is a comparison of bare hands (B) to gloved hands (G) for a control and cold conditions (Glitz et al., 2009).

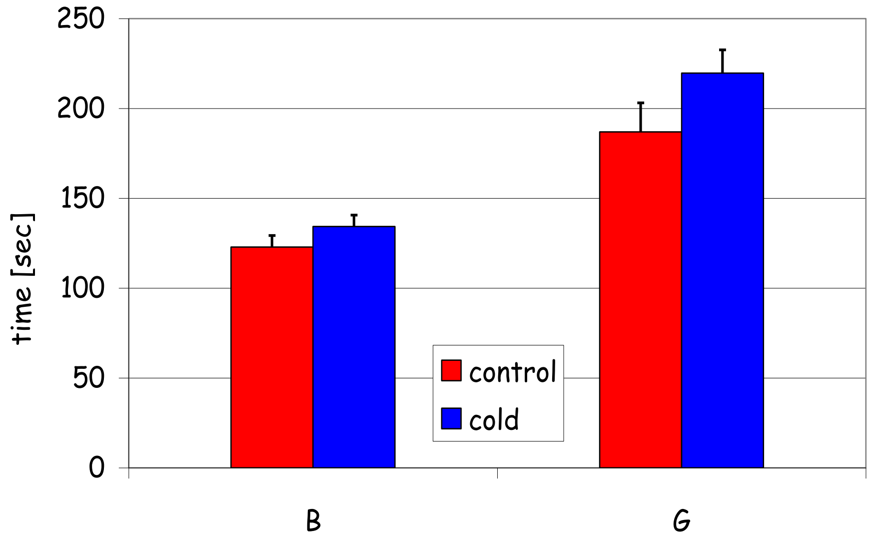

Figure J-1. Cold hand vs. wearing gloves on finger dexterity.

The results in Figure J-1 show the completion times for a screw/bolt skill test with bare hands (B) or gloved hands (G) under control and cold conditions. With skin temperatures of 10 °C or below, the study found no significant difference between the bare hands in the control environment and the cold. The gloved hands however, had significantly different completion times compared to bare hands, suggesting that the loss of dexterity due to gloved hands may be more of a concern than loss of dexterity due to cold hands, at least for the gloves used in that study. Figure J-2 shows a picture of the gloves used. They are military five-finger gloves, equipped with a three-layer laminate insert. The back of the gloves is made from five-color camouflage fabric; the palm is goat leather.

Another study conducted by Brajkovic et al. (2001) used a gross finger dexterity task to compare bare hands to thinly gloved hands in cold conditions. The participants performed a C-7 rifle assembly task that took approximately 1-2 minutes. The hands were subjected to 25 °C ambient temperatures. The results found little difference in task time for the bare hand versus thinly gloved hand in cold, at least using thin, cotton-based gloves.

Figure J-2. Gloves used in finger dexterity study.

The two studies taken together appear to support the conclusion that the impact of gloved hands, using bulky gloves, is a greater concern with respect to loss of dexterity, than cold hands. The gloves used in the RDC VDSD testing study are similar to the type of gloves in Figure J-2 and are considerably thicker than the ones used by Brajkovic et al. (2001). Based on the results of these two studies, we may be able to assume that conducting usability testing with gloved hands will result in similar or somewhat slower performance as compared to bare hands in a cold environment.

APPENDIX K PHYSICAL TESTS AND MEASUREMENTS

The float and submersion tests were conducted in a conference room under the same conditions: air temperature was 70 °F and water temperature was 65 °F. The drop tests were held outdoors on 28 November 2011 with an air temperature of 57 °F. Devices were left outside for 1 hour prior to the drop testing to acclimate to the conditions. Devices were dropped from a height of 8 ft onto a 6”-thick concrete slab. The devices were dropped in a “signal-down” orientation and, in most cases, the device impacted the concrete in the same orientation. In one case, because of battery orientation/weight, the device flipped in midair and did not land on the lens but rather on the opposite end.

All devices (14 in total) for the usability testing were weighed and their respective times to illuminate were recorded. The lightest device was measured at 2 oz while the heaviest weighed 28.5 oz. Battery types were also logged. Table K-1 shows the results of these measurements.

Table K-1. Device weights; battery type and time to illuminate.

Device	Battery Type	Weight w/Battery	Time to Illuminate (sec)	Notes
4	self contained	2 oz	0.5	
10	1 lithium C cell	4.5 oz	1.2	
6	self contained	2.5 oz	0.8	
8	2 AA alkaline	5.5 oz	0.8	
20	sealed lithium rechargeable	28.5 oz	0.7	
7	2 AA alkaline	4.4 oz	0.9	
1	1 D cell	8 oz	1.1	
12	2 AA alkaline	6 oz	instantaneous	
14	1 C cell alkaline	7 oz	1.5	Cold energize seems to take longer than once warmed up
13	2 AA alkaline	4 oz	1.1	
11	2 AA alkaline	4.5 oz	1.1	
18	1 CR 123	4 oz	1.2	
19	2 CR 123	5.8 oz	1.1	
9	1 C cell alkaline	5.5 oz	1.3	

Next, the devices were put through the float and submersion tests. Each device was placed into a large (5 gal) bucket filled with a foot of water and the float results were recorded. After the float test, each device was submerged for 1 minute then removed from the water. Each device was then energized and examined to see if the device still functioned and if any water had penetrated it. Table K-2 shows these results.

Table K-2. Float and submersion test results.

Device	Float	Illuminate after Submersion	Notes
4	No	Yes	Activates once in water (with switch on)
10	No	Yes	Brighter with lithium battery
6	No	Yes	
8	Yes	Yes	
20	Not tested	Not tested	Weight would suggest no float
7	No	Yes	
1	No	No	Initially turned on; some water droplets inside lens. After sitting overnight, condensation appeared in lens and water in battery housing; light no longer worked
12	No	Yes	
14	No	Yes	
13	No	Yes	
11	No	Yes	
18	No	Yes	
19	No	Yes	
9	No	Yes	

Finally, a drop test was conducted. Each device was dropped (lens down) onto a concrete slab from a height of 8 ft. After the drop, each device was examined, photographed for damage, and energized. Table K-3 show the results of this test.

Table K-3. Drop test results.

Device	Illuminate after Drop	Damage	Notes
4	Yes	No	Lightweight, no visual damage
10	Yes	Yes	Small scratches, dents on lens
6	Yes	No	No visual damage
8	Yes	Yes	Small scratches, dents on lens
20	Not tested	Not tested	
7	Yes	Yes	Scratches on lens
1	No	Yes	Bulb smashed, scratches and cracks on lens
12	Yes	Yes	Scratches on lens
14	Yes	Yes	Scratches on lens
13	Yes	Yes	Small scratches, dents on lens
11	Yes	No	No visual damage
18	Yes	Yes	Scratches on lens
19	Yes	Yes	Small scratches, dents on lens
9	Yes	Yes	Small scratches, dents on lens